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PATUXENT RIVER, MARYLAND 20670-5304

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ABRIDGED PROCEDURAL GUIDE TO AIRCREW ANTHROPOMETRIC ACCOMMODATION ASSESSMENT

by

Mr. Scott A. Price

Systems Engineering Test Directorate

14 April 1993

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DEPARTMENT OF THE NAVY
FLIGHT TEST AND ENGINEERING GROUP
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This Technical Memorandum is the result of research and field testing experience performed to standardize procedures for the evaluation of Aircrew Anthropometric Accommodation Assessment. This effort was originally conducted for NAVAIRSYSCOM and the T-45A Program under AIRTASK A5115114/053C/2W11420000, Work Unit A5114D-21.

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NAVAIRSYSCOM (AIR-531) tasked us to investigate and develop new procedures for determining the ranges and limitations of anthropometric accommodation in military aircraft. These procedures quantify what types of aircrew - based on their body's morphologies - are able to safely and efficiently operate a particular crewstation in an operational environment. Aircrew Anthropometric Accommodation Assessment provides detailed, repeatable methods for obtaining the accommodation data needed to determine this. Results are plotted to determine the full range of anthropometric values and their relationship to pilot/aircrew "fit" for a number of important areas. Use of Aircrew Anthropometric Accommodation Assessment enables the establishment of Anthropometric Restriction Codes, reduces the need for fit-checks, guides Student Naval Aviators into appropriate pipelines, determines contractor compliance with design goals, and identifies deficiencies in the crewstation layout of mockups and aircraft undergoing development.

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SUMMARY

NAVAIRSYSCOM (AIR-531) tasked us to investigate and develop new procedures for determining the ranges and limitations of anthropometric accommodation in military aircraft. These procedures quantify what types of aircrew - based on their body's morphologies - are able to safely and efficiently operate a particular crewstation in an operational environment. Aircrew Anthropometric Accommodation Assessment provides detailed, repeatable methods for obtaining the accommodation data needed to determine this. Results are plotted to determine the full range of anthropometric values and their relationship to pilot/aircrew "fit" for a number of important areas. Use of Aircrew Anthropometric Accommodation Assessment enables the establishment of Anthropometric Restriction Codes, reduces the need for fit-checks, guides Student Naval Aviators into appropriate pipelines, determines contractor compliance with design goals, and identifies deficiencies in the crewstation layout of mockups and aircraft undergoing development.

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INTRODUCTION

PURPOSE

1. The procedures for Aircrew Anthropometric Accommodation Assessment (AAAA) were developed to quantify what types of aircrew - based on their body shapes and sizes - will comfortably, safely, and efficiently fit into an existing crewstation. AAAA relates a set of defined and readily obtainable anthropometric body measurements to the layout and operational considerations of each crewstation in an aircraft. This provides a detailed description of which aircrew will encounter restrictions in an operational environment due to the interaction between anthropometric dimensions and crewstation layout. Interpretation of AAAA results is based on a comparison of an individual's or population's anthropometric measurements to the anthropometric ranges that are accommodated/not accommodated.

2. AAAA procedures define data for aircraft anthropometric comparison/restriction systems such as Anthropometric Restriction Codes (ARC's), demonstrate deficiencies in the crewstation layout of mockups and aircraft undergoing development, determine contractor compliance with design goals and specifications, reduce the need for fit-checks, and guide Student Naval Aviators into appropriate pipelines.

GENERAL OVERVIEW

3. The intent of AAAA is to determine what access or clearance is provided for any given person. Successful accommodation is quantified through amounts of functional reach, field of view, leg clearance, etc. that are obtained. Unsuccessful accommodation is quantified through amounts of obstruction, miss distance, lack of clearance, etc.

4. AAAA procedures "map" the effects of a full, realistic range of anthropometric measurements against the layout and operational constraints of an aircraft cockpit or crewstation. The goals of sufficient workspace volume and safe egress paths frequently conflict with the goals of visual and functional access to controls and displays. The tabulated and graphed results from these procedures will demonstrate this conflict. They show which types of people can fit into which crewstations, based upon anthropometric descriptors and the operability requirements of the aircraft.

5. The result is an empirical description of aircrew accommodation based upon an anthropometric dimension or the multivariate relationships between dimensions. This provides absolute minimum and/or maximum values (such as a maximum permissible sitting height before contact with a canopy occurs), degrees of accommodation for aircrew with dimensions beyond these values, or ratios (such as the percentage of a display obstructed by the glare shield, dependent upon sitting eye height).

6. These procedures are based on numerical values. Potentially related areas of evaluation such as functional grouping, control logic, display legibility, and many others are not specifically addressed here. Other areas such as cone of vision and accidental actuation are an implicit addendum to these procedures. AAAA is a stand-alone set of procedures for one specific area of aircraft evaluation: anthropometric accommodation. Other evaluations can be interwoven for concurrent testing, if needed.

7. AAAA procedures maintain a perspective on the real-world limitations in aircraft test time, funds, and number of subjects. Instruments and measurement techniques are readily available. Unusual, custom-made devices and body segment supports or restraints were not pursued so as to make these techniques accessible to a wider audience of engineers and anthropometrists. This report is also intended to be instructional for engineers not familiar with anthropometric techniques, although it is by no means a replacement for an education in anthropometric issues and actual experience in the field.

8. AAAA was originally created for use on fixed wing aircraft. However, it is inclusive enough to be useful for rotary wing aircraft with little or no modification. The concepts and procedures provided here can also be directly adapted to land-based vehicles and workstations.

RESULTS AND CRITERIA

9. The main objective of AAAA is to determine the varying effects of a full anthropometric range upon a specified area of concern. This report is not primarily concerned with the interpretation of these data, although that is the crucial final step in relating the testing and measurements to real world mission requirements. General guidelines are given throughout this report for data interpretation, but determination of the specific criteria for a particular aircraft is left to the testing engineer, anthropometrist, or an independent group. This interpretation is often aided through consultation with the operators (i.e., pilots).

10. Evaluation of the data's validity and reliability should always be considered independently from aircraft mission and operational requirements. The best approach is to perform all of the evaluations first. This is followed by determining specific requirements and relating the data to those requirements. Prior knowledge of minimum requirements only increases the likelihood of an evaluator altering datum or choosing more "appropriate" datum during the course of testing, thereby reducing overall validity.

11. This approach also encourages testing throughout the full range of seat positions and anthropometric dimensions. Graphing these data with regression lines beyond the "just acceptable" level will provide information for future comparison to new requirements and demonstrate the effects of cockpit design/layout changes. Specific recommendations for appropriate aircrew anthropometric ranges are also determined for the ARC (reference 1). However, these AAAA procedures are intended for determining a more complete, graphical "mapping" of the crewstation throughout the Development, Test, and Evaluation cycle.

IMPORTANT NOTE

NAVAIRSYSCOM NO LONGER ENDORSES THE USE OF MOST MILITARY SPECIFICATIONS AND STANDARDS FOR DETERMINATION OF ANTHROPOMETRIC ACCOMMODATION

SUBJECTS

SELECTION

12. In selecting subjects for test sessions, evaluators must first consider the target population and a sampling strategy. Most situations will dictate that a specified range be investigated, but unique characteristics of the aviator/aircrew population must be incorporated into the subject selection process. For instance, will women be flying the aircraft? If so, will there be a recognized, permissible lower limit on the female anthropometric range of values? Will foreign aviators/aircrew be using the aircraft? Is there a breakdown of anthropometric data available which represents a statistical summary of the population's anthropometric characteristics, and also which helps determine how each subject compares to the population as a whole?

13. The target population for an aircraft may actually be a subset of the entire population, sometimes specified in percentiles (such as "5th to 95th percentile Naval Aviators"). "Percentile" refers to the percentage of the total population who have their measurement of a particular anthropometric dimension less than or equal to a specified measurement value. For instance, a 95th percentile sitting height is equal to 38.36 in. for the population of Naval Aviators used in the NAEC-ACEL-533 1964 Navy anthropometric study (reference 2). This indicates that 95% of the total population in the study had a sitting height less than or equal to 38.36 in. Specific anthropometric measurements can be found for a desired percentile when using data bases that summarize percentile information. Likewise, a specified percentile in the population can be equated to an exact dimensional measurement. It is becoming more common to refer to a percentage of the overall population that should be accommodated. This differs from strict percentile qualifiers in that a given percentage of the total population (for example, 90%) will have some anthropometric dimensions beyond the limits of a general percentile restriction statement (such as 5th-95th percentile).

14. After the population and its general characteristics have been determined, subjects must usually be selected from a limited pool of people. Although not ideal, this may result in a sampling from coworkers and affiliated contractors. Close matches to desired anthropometric dimensions may require a larger scale search and an accompanying data base of dimensions, but this may be preempted by time and funding constraints. The optimum subject pool is from actual aircrew, although this can be difficult due to scheduling conflicts and a small number from which to choose. Aircrew are preferred since they are knowledgeable about realistic body positioning, activating and using aircraft systems, potential problem areas, and mission relationships. If there is an insufficient number who fly the particular platform being evaluated, aviators and aircrew from other platforms would be preferable to using nonaircrew subjects.

15. After the actual aircrew population and the pool of subjects have been determined, the desired anthropometric test cases are considered. The selection of subjects is determined from the anthropometric descriptions of the desired population for each particular aircraft. The design goals for the aircraft may be expressed in terms of multivariate test cases (the currently preferred method) with specific values, numerical ranges of anthropometric values, or percentiles. These provide a basis for extremes in subject anthropometry that should be sought and used.

16. A basic minimum selection of subjects should represent the following generic morphological descriptors for the population under consideration: short/thin, short/heavy, tall/thin, and tall/heavy. Therefore, every study should have a bare minimum of four subjects. The actual number of subjects the evaluators decide to use will depend on the level of confidence desired and the need for an adequate sample size from which to make inferences. If time and funds permit, another small and large subject should be added. If one or two more subjects are allowable (for a total of seven or eight), they should be representative of the middle range of the population. Although mid-range subjects generally do not experience the more significant problems in accommodation, their data will assist in interpolating the graphs between datum. A larger group of subjects than eight should have the anthropometric dimensions spread throughout the population range, with special emphasis on the extremes where most problems occur.

17. Artificial increases in a subject's dimension(s) can be created during the test sessions (see Artificial Anthropometric Extrapolation section, paragraphs 32 through 39) to compensate for a small group of subjects. However, reliance upon a larger group of subjects is more accurate, yielding a more repeatable and representative body of results.

CLOTHING/GEAR

18. Typical clothing and gear worn by the aviators and aircrew need to be included in the test sessions. Clothing and gear cause movement restrictions, add bulk, and change the overall dimensions of the subject.

19. All flight gear detailed in the aircraft's NATOPS, or provided as Government Furnished Equipment, should be worn to simulate actual flight restrictions. The evaluators should acquire beforehand all winter (and summer, if needed) flight gear, handwear, headwear, and attachments (flashlight, kneeboard, etc.) needed for the crewstation being evaluated. Depending upon the aircraft and its missions, most evaluations should be performed with the subjects wearing winter flight gear. However, at least some testing should be done to represent "worst case" flight gear such as exposure suits or Chemical/Biological/Radiological (CBR) ensembles. This information can provide conversion factors from the data acquired while wearing more typical gear, as well as providing distinct datum.

HANDLING SUBJECTS

20. Full management support will be necessary in acquiring subjects. Conflicting schedules and workload can make the selection process difficult unless this support is given. Some subjects may also be ideal in their dimensions, but unreceptive to participation in the evaluations. Disruptions to work schedules, aircraft schedules, and other testing require an ensured prior commitment from all involved.

21. Although AAAA procedures are designed to be as objective as possible, the evaluators must be vigilant to differences in measurement caused by subject personality. Some may be reluctant to participate (resulting in minimal effort at reaching for a button, for instance) while others may be too eager (stretching beyond the range of generally acceptable comfort, for instance). Subjects with little investment in the project may act disinterested and be unspecific in their observations. Evaluators should also watch for subjects, especially experienced aircrew, who may give specific complaints too much importance, be offended by new or unusual equipment, or have points to make that stem more from personal perspective than actual flight or mission relations.

22. During the course of testing, evaluators need to be aware of their own conduct and its effects on subject response. Professional dress and behavior tend to increase subject confidence. Pleasant and respectful demeanor creates a good working relationship. An informative briefing beforehand increases the potential response rate for the number of volunteer subjects and also increases motivation during the evaluations. Comfortable, confident, motivated subjects tend to hold their positions better and be more receptive to expanded test sessions. When measuring to points on the subject's body, the evaluator's touch should be firm to project confidence and put the subject at ease. Also, precede a touch to potentially sensitive areas with a warning.

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ANTHROPOMETRY

ANTHROPOMETRIC MEASUREMENTS

23. Anthropometric body dimension measurements on subjects should be performed (or at least supervised) by an experienced anthropometrist, aviation medicine technician, or aviation physiologist. Obtain and properly calibrate (if required) professional quality anthropometric measuring devices. Typical devices include a GPM anthropometer, base plate/foot locator, sliding caliper, sliding caliper (Poech type), rounded spreading caliper, Bicondylar Vernier caliper (Holtain caliper), and 2 meter steel measuring tape. All distance measurements (for both anthropometric body dimensions and accommodation assessments on aircraft) are measured to the nearest tenth of an inch.

24. All measurements require explicit descriptions of the measurement techniques used. Current Navy methods differ from those used in the outdated Anthropometry of Naval Aviators-1964 (NAEC-ACEL-533), as well as those used by other military services, contractors, and foreign studies. Each dimension is defined by a specific name, point of origin, point of termination, and procedural description including any unusual notes or cautions.

25. Current Naval Aerospace Medical Institute measurement techniques should be used, but specified and consistent techniques are the most important factors. The current methods are appropriate for mockup evaluations, general cockpit mapping, and ARC. However, all of the AAAA procedures can be applied to other anthropometric measurement techniques and data bases.

26. It is important that project engineers and anthropometrists be aware of the differences between current and NAEC-ACEL-533 methods if percentiles or general population information is taken from the 1964 study. Percentiles from NAEC-ACEL-533 are frequently referenced, although there is debate as to its currency for modern aviator populations. If time and ability permits, measurements can be taken using both methods for future reference and comparison purposes.

DIMENSIONS/ANTHROPOMETRIC DESCRIPTORS

27. Consider all anthropometric dimensions for applicability to AAAA. Evaluators should relate critical applications, tasks to be performed, and potential problem areas driven by anthropometric considerations. The project team should determine a list of required anthropometric dimensions, and all measurements from this list should be performed on each subject. Explicitly describe all body dimension characteristics, subject body position, and body (or flight gear) landmarks for each measurement to increase repeatability.

28. Here is a recommended list of anthropometric dimensions and general information to acquire from every subject. If a subject is significantly asymmetrical, then both sides should be measured (such as measuring both the left and right legs for functional leg length). Names for dimensions may vary by the techniques or data bases used.

name (consider privacy/anonymity issues)
sex
age
race
height (stature)

weight
sitting height
sitting eye height
trunk height (sitting acromial height)
functional arm reach
vertical downward reach
vertical upward reach
buttock-leg length (functional leg length)
buttock-knee length
sitting knee height
shoulder width (bideltoid breadth)
sitting hip breadth
thigh circumference
lower thigh circumference
hand length, breadth, circumference, or other as needed
boot size
(as needed: flight gear dimensions and effects)

CAVEATS

29. Project personnel should be aware of the complexities and vagaries inherent in anthropometric studies. People are flexible in their motions and can interpret body positioning in different ways. Test sessions on different days can cause differences in measurer technique and subject response; the longer the time period, the more likely this effect will be significant.

30. Relating multiple dimensions is inherent to full body anthropometric studies. Anthropometric dimensions have complex interrelationships that should be recognized as difficult to generalize due to the high number of variables. Accommodation rates may underestimate or overestimate truly acceptable population ranges. This is due to the effects of interacting multiple dimensions or extraneous aspects of combining AAAA findings with operational requirements. These procedures use the most relevant and logical dimensions, but dimensions not discussed can also create effects not measured or considered here.

31. Caution should be observed in condensing the findings down to absolute minimum/maximum values required for effective operation of the aircraft. This does not fully consider a whole person connected to the dimension of interest, therefore not accounting for the widely varying dimensions throughout an individual's body. Also, the relative location and interplay of various body dimensions change as the seat is moved up or down, forward or aft. Angles and orientations at the foot, knee, hips, shoulders, neck, and other locations will change at varying seat positions. Most importantly, the tradeoffs that a person experiences at any given seat position are not considered by condensing the results down to just anthropometric limits without relating it to varying seat positions and other areas of concern. People really only sit at one seat position at a time, yet these absolute values are generally derived from the worst case across the full range of seat positions. For example, the minimum sitting eye height permissible at the top seat position for acceptable over-the-nose external field of view has no direct relationship to the maximum sitting height permissible at the bottom seat position for overhead clearance. The situations involve different people, measurements, seat positions, and anthropometric relationships.

ARTIFICIAL ANTHROPOMETRIC EXTRAPOLATION ("BLOCKING")

32. Artificial extrapolation of a subject's anthropometric dimensions, frequently referred to as "blocking", is done to increase the data obtainable from a limited number of subjects. In effect, certain dimensions are artificially lengthened to create a "new" subject with a new set of dimensions. Blocking can be used to simulate body segment dimensions which are greater than those that the subject actually possesses. AAAA tests are then repeated on the blocked subject to provide another set of data and observations. This approach helps compensate for limited time, funds, and/or subjects available to an AAAA study.

33. Blocking can be used in the following test areas: overhead clearance, external field of view, internal field of view, functional arm reach, functional leg reach, leg clearance, ejection clearance, and other more specific areas. As an example, buttock knee length and sitting knee height can be blocked to provide the large amount of data needed to make the bivariate and trivariate relationships inherent in leg clearance and functional leg reach assessments.

34. Using the methods described in this report should reduce the need for blocking. A project using a large number of subjects can generally avoid blocking entirely if subjects are found to represent the required anthropometric extremes. Data analysis is set up for mathematical extrapolation and interpolation of anthropometric datum. This has been demonstrated through experience to be frequently as accurate (sometimes even more accurate) than artificial blocking in the field.

35. Determination of the amount of artificial extrapolation should be done by measuring the actual position in three-dimensional space of a body landmark which acts as an origin or termination for the anthropometric dimension that is being artificially increased. These measurements should be taken before and after blocking to determine the delta that a particular dimension has truly increased. Simply using standardized block sizes will likely not be accurate enough. Blocking material can compress under a subject's weight. The blocking material's shape changes the body's weight distribution across a seat cushion. Also, since blocks are frequently larger than the contact area of the body on the seat, weight will be displaced across a larger area and the cushion will not compress as much as it would with a nonblocked person. A device such as Space Vector (a three-dimensional point location device using transducers) or a triangulation from cockpit hardpoints is used to determine these three-dimensional displacements.

36. There are three primary areas for blocking: under boot, under buttocks, and behind the hips/lower back. Blocking under the boot increases sitting knee height and functional leg length; applicable tests include functional leg reach, leg clearance, and ejection clearance. Blocking under the buttocks increases sitting height, sitting eye height, and acromial shoulder height; applicable tests include overhead clearance, external field of view, internal field of view, and functional arm reach. Blocking behind the hips/lower back increases buttock-knee length and functional leg length; applicable tests include functional leg reach, leg clearance, and ejection clearance.

37. The set of blocks includes thicknesses of 0.5 and 1.0 in. and should be shaped appropriately. Boot blocks should maintain the basic shape of the bottom of the sole. Offset heels can cause problems and may require separate (but equal thickness) blocks for the forward and heel sections of the boot. Attach these blocks by wrapping tape or velcro around the block/footwear combination. Evaluators

should be aware that boot blocks may hinder normal foot positioning, especially if pedal toe guards are used. Buttock blocks should be approximately U-shaped to help realistically distribute the weight applied from the buttocks and upper thighs. Hip/lower back blocks should be approximately rectangular. Buttock and hip/lower back blocks may need to be trimmed for proper fit into the seat pan and around connections or restraints.

38. Blocking has, in some cases, produced anomalies in results. Preliminary AAAA testing showed that blocking occasionally skewed results, altered regression equations, and did not match up with datum from a subject with the actual anthropometric dimensions that were being simulated. By an unofficial consensus, most previous methodologies for anthropometric accommodation have recommended that blocking not exceed 1 in. However, this limitation appears to be arbitrary and intuitive and has not been verified by empirical studies. For consistency, this report will also recommend that blocking not exceed a maximum dimension increase of 1 in. Project personnel should be aware that blocking greater than 1 in. may significantly distort body segment relationships.

39. For related reasons, seat repositioning has been recommended in some other versions of accommodation assessment techniques. This was done to create artificial vertical increases in sitting height, sitting eye height, and sitting acromial height. Forward/aft movements have also been recommended for increasing buttock-knee length and functional leg length. This approach can be used for some coarse adjustments and observations, but seat positions and anthropometric dimensions do not necessarily move in equivalent planes and may not be directly additive. Angles in the seat do not necessarily produce strict up/down, forward/aft motions and they may not correlate to direct increases or decreases in anthropometric dimensions. If the geometry of the seat is completely accounted for, seat repositioning can provide estimates, however. This may be useful if, after all test sessions have been completed, an estimate is needed for particular anthropometric dimensions that were not represented in the subject pool. Such estimations are a variation on the extrapolation and interpolation recommended for filling in information beyond subject datum.

PROCEDURAL TOPICS

PROJECT PERSONNEL

40. Proper training is essential for project personnel performing the measurements and making observations. If possible, instruction should be provided by a person with experience in both aircrew accommodation and anthropometric issues. Information, practice, observation, and feedback should be provided in the following areas: purpose and background of the project, basic anatomy (as needed), body and flight gear landmarks, anthropometric dimensions, use of equipment, subject handling, importance of data quality, and error control. It is the responsibility of the observer, not the subject, to ensure proper body positioning at all times.

41. In the likely event that multiple evaluators will work on the project, errors and problems created by using more than one evaluator need to be minimized. Although having multiple evaluators decreases fatigue-induced observer error and increases the speed of processing subjects, interobserver error will occur. Measurement methods need to be understood and agreed upon before testing begins so there is no independent interpretation of the procedures and so that divergent working habits are minimized.

RELIABILITY

42. Data reliability is dependent upon having well-defined procedures, an understanding of objectives and procedures by project personnel and subjects, and strict adherence to procedures with any deviations fully noted. The large number of variables inherent in anthropometric studies can be combated by closely following rigid procedures. However, if project personnel should try to make the results even more repeatable by restraining or moving body segments for the subjects, the benefits of repeatability may be offset by the nonrealism in subject positioning and movements.

43. Reliability is also affected by multiple observers, subject body positioning, subject differences not included in the major criteria dimensions, and measuring techniques. Reliability and tolerances affect predictions for engineering/design purposes as well as the additivity and/or relationships between anthropometric models and measurements.

44. Arrange staffing schedules so as to decrease fatigue and observer error. Take the following into consideration when deciding on grouping and relative ordering of the different test areas: instruments used, subject position, evaluator position, subject fatigue from either holding a particular position or participating for a long period in the cockpit/crewstation, evaluator fatigue, time-motion efficiency, and data editing combinations. The AAAA procedures detailed ahead are arranged in a general head-to-toe order; actual ordering of the different test areas is determined on a case-by-case basis by project personnel.

EQUIPMENT

45. Measuring instruments and other equipment brought to an aircraft should always be standardized, validated, and calibrated. The following is a minimum equipment list:

calculator
(for calculations in the field)
Abney level
(for determining up/down visual elevation angles)
optical protractor
(for determining left/right visual azimuth angles)
digital inclinometer
(for determining seat geometry and ejection lines)
inside diameter caliper
(for measuring clearances and miss distances)
flexible metal measuring tape
(preferably with a scale in tenths of inches)
(for distance measurements)
1 ft rigid straightedge ruler
(preferably with a scale in tenths of inches)
(for distance measurements)
3 ft rigid straightedge yardstick
(for extrapolating ejection lines of knees and feet)
small foam sections
(for placing on head or helmet to determine clearance)
duct tape
(for attaching foam and blocking pads)
masking tape
(for marking specific seat positions on rail or tracks)
"blocking" pads
(for artificially increasing anthropometric dimensions)
video camera with tripod and spare tapes

46. Video cameras have demonstrated their usefulness in answering questions about data charts, the validity or reasons behind unusual datum, measurement techniques, procedural deviations, aircraft configuration, subject positioning, and between-subject differences. They should be used on the aircraft during all test sessions. A video camera can be hand-held for closeups, measurement values, measurement techniques, references to cockpit hardpoints, depictions of obstructed areas, subject positioning, and other visual notes. The camera (or a second camera) can be placed on a tripod for an overall view, as well as for a recording device for measurements and observations.

AIRCRAFT REQUIREMENTS

47. The cockpit or crewstation being evaluated will need to be in the desired production configuration with representative dimensions and instrumentation. Potentially dangerous control mechanisms such as ejection devices, canopy shattering systems, or emergency landing gear handles will need to be deactivated or safed. More extensive coordination will be required if the control interfaces for these devices will be actuated during testing. In any case, ground crews familiar with all aspects of aircraft operation should be available for briefing on "seat checkouts", potential dangers, and any problems or questions encountered during testing.

48. Hydraulic power will be needed for full control movements of a yoke or other hydraulically actuated controls. Precautions will need to be taken regarding the effects of moving such controls with the aircraft on the ground to protect aircraft equipment and people in the vicinity. Electric power to the aircraft will be needed for electrically powered seat movements as well as any special considerations for lighting, instruments, and displays.

DEFINING AIRCRAFT SEAT INFORMATION

49. To allow comparison against cockpit/crewstation design/specifications, aircraft configuration changes, or future AAAA test sessions, well-defined measurements should be taken from seat hardpoints to cockpit/crewstation hardpoints. Specific, repeatable seat positions should be located. The following positions deserve special attention: neutral seat reference point (NSRP), full up, full down, full forward, and full aft. The NSRP acts as a standardized point from which to take seat position measurements, therefore allowing continuation or refinement of AAAA testing on other aircraft of the same airframe type. The other locations help describe the full range of adjustability provided by the seat. Determination of these positions is especially useful for quantifying interaircraft production variability, as well as for possible causes of otherwise unexplained differences between testing sessions on more than one of the same type aircraft.

50. The NSRP can be determined from contractor diagrams and descriptions. Special markings on the seat may be present or locations can be triangulated. Note the exact seat and cockpit/crewstation hardpoints with their measurements for future reference. This seat position serves as a zero point from which seat movements occur in a positive or negative direction (defined here as positive for up and/or forward, negative for down and/or aft). Also define the plane through which seat movements are measured. For instance, in an ejection seat aircraft limited to up/down movement on a reclined rail, the up/down movements can be defined in terms of a vertical plane perpendicular to a reference in the aircraft (such as the cabin floor or aircraft waterline) or it can be measured directly along the plane of the rail. This latter method has proven to be much simpler and quicker since it does not require conversions and can be measured directly by seat travel along the rail. If needed, geometric conversions can be made later.

51. Since all of the accommodation checks will be taken at multiple seat positions throughout the range of seat travel, a consistent separation distance between test positions will need to be determined. Continuously adjustable seats that move only along a single line of motion (such as motorized ejection seats moving along a rail) should have test positions approximately every inch, with a minimum of four distinct seat positions. Rail angle and the overall extent of travel should be noted. Masking tape can be applied along a visible, stationary section on or near the ejection rail. Seat positions can be determined by observing a seat hardpoint that moves across the tape as the seat is moved. NSRP and +/- incremental distances from NSRP should be marked on the tape relative to the movements of the seat hardpoint "pointer".

52. Seats with notched position adjustments should use the notches as test points. Distances between notches, the number of notches, and direction of seat motion should be noted.

53. Seats with forward/aft motion will use the same type of position location as described above. For seats that combine both forward/aft and up/down motion, seat positions should be noted in an x-y format (with the x value representing the +/-

forward/aft position, and the y value representing the +/- up/down position). Seats with lateral motion are unusual, but movements could be quantified using the same techniques in an x-y-z format.

54. For seats with the option of a seat tilt and/or swivel adjustment(s), the seats will either need to have a predefined orientation maintained throughout testing or the tilt/swivel components will need to be quantified through geometric means (x-y effects or angles around an axis). This should be determined on a case-by-case basis since the evaluators will need to determine the significance of the tilt component's effects on anthropometric accommodation in both the testing and operational environments.

55. As is the case with most testing and experimental situations, more data are more beneficial than fewer data. However, the exact number of individual test positions should be determined by balancing this with the needs for expediency and for reduction in essentially overlapping positions.

SEAT RELATED PROCEDURES

56. The aircraft's seat acts as the one common point that connects all of the accommodation tests to each other. All tests in the sections ahead describing AAAA procedures are to be performed in a specified order from an individual starting seat position (such as the full down position). When this iteration of all tests is completed, the seat is moved to the next position of interest and all of the procedures are repeated. This process is iterated throughout the full range of seat travel at each predetermined seat position.

57. The rationale for this approach is to obtain as complete a range of data as possible, even though some sitting positions may be highly unrealistic for a particular subject. Limiting subject positions to approximating a Design Eye Position (DEP), for instance, would not account for the reality that most aircrew need to adjust the seat so they are away from DEP to compensate for reach, clearance, or field of view deficiencies in the cockpit/crewstation design. More importantly, these data build the foundation for complete graphs that, through extrapolation and interpolation of data, essentially "maps" the anthropometric relationships to the cockpit/crewstation being evaluated.

58. Even if the aircraft should appear to successfully accommodate most of the population, the iterations throughout the full seat range should still be performed. Performance limitations beyond expected anthropometric extremes should be determined for the following reasons: informational and research purposes, data on permissible extremes, accommodation comparisons to other aircraft, and future references needed for evaluating the anthropometric accommodation effects of layout or structural changes to the aircraft.

59. Given a limited amount of time on an aircraft, the priority should reside with testing as many subjects as possible. Extremes in seat positioning or use of small seat position increments may need to be sacrificed. However, limited subjects but ample time may allow finer seat position increments or multiple passes through critical test iterations for repeatability/error checking and more precise averaging of results.

60. Each subject should be assisted in adapting, connecting, and adjusting the flight gear, attachments, and any special mission equipment to the seat. During the course of testing, the evaluators should constantly be vigilant to each subject's

positioning and posture relative to the seat. Generally, the hips should be moved back into the seat and the shoulders should be back but comfortable and not rigid. However, evaluators should also assist subjects in acquiring and maintaining restraint conditions (such as tightly locked, loose, etc.) and body positions (such as head and shoulders full back, full forward reach with harness loosened, twisting for increased aft field of view, etc.) that are representative of other important operational conditions and requirements. The harness, leg restraints, and other fittings should be properly positioned and locked in place.

DATA REVIEW AND ANALYSIS

61. As mentioned above, a key to obtaining useful results is in getting a full range of data throughout the seat's travel for increased validity in the extrapolations and interpolations performed to effectively "map" a crewstation. This helps refine the regression equations used to estimate results for the general population or for people whose dimensions do not exactly match those of the subjects used.

62. Data-taking forms are included in appendix A. These forms make datum quickly accessible for project personnel in the field. They are arranged so that data can be monitored for logical trends (increasing, decreasing, or constant trends and their relative ratios or incremental changes) along the rows and columns of each table. Anomalies can be caught and rechecked. Project personnel may also want to compare forms for logical trends between small and large subjects and for appropriate magnitude differences. Metric units have increased precision, are a scientific standard, provide comparability with foreign studies, and decrease rounding error. However, Navy studies have historically used the U.S./English standard units and are therefore recommended.

63. If a sufficient number of subjects and data are available, summary statistics can be useful for descriptive purposes. Standard information should include the following values: N, mean, median, standard deviation, minimum, maximum, skewness, and kurtosis. Proportional models and regression equations should also be described (this includes variation interpretation of correlation, probability of slopes, standard error of estimate, and various regression equations). Statistical summaries and raw data should be maintained in a tabulated form for efficient reference at a later date. Statistical packages such as Minitab, SAS, SPSS, STATA, and Systat can be very beneficial, especially for large amounts of data.

64. Post hoc editing of data should be minimized, although it is useful for deleting obvious mistakes or outliers. Post hoc editing is generally accomplished by either checking against an appropriate range of values, comparing against regression equations, or determining deviations from data norms.

GRAPHING DATA AND INTERPRETATION

65. Anthropometric accommodation in any crewstation results from a series of highly interrelated tradeoffs between the effects of an individual's different anthropometric dimensions. To relate all of these different dimensions to repeatable hardpoints, these procedures revolve around making evaluations at defined seat positions. Tests can therefore be performed at different times using different subjects, allowing direct comparison between all data taken from the same seat positions.

66. In an effort to understand the tradeoffs involved, consider the following situation: After a pilot positions his or her seat to a particular location, many effects happen because of his or her particular range of anthropometric dimensions. If the pilot needs to raise the seat to get more external over-the-nose field of view, he or she may increase the likelihood of overhead contact, obscure instrument view beneath the glare shield, decrease the ability to reach lower controls on the main instrument panel (MIP) and consoles, cause shin contact with the lower MIP, and/or lose the ability to make full yaw pedal throw and brake rotation. If the pilot needs to lower the seat to see an instrument obscured by the glare shield, he or she may significantly decrease external field of view, cause shin contact with the lower MIP, produce excessive thigh gap to the seat, and/or restrict the flight stick's range of motion.

67. Also, people are not perfectly proportional. They do not represent consistent percentiles across all of their anthropometric measurements. An individual may have a 5th percentile sitting height but also have a 45th percentile buttock knee length. In other words, there are 5th percentile values but not overall 5th percentile people. A particular small percentile dimension tends to underestimate the entire body, whereas a large percentile dimension tends to overestimate. To make the results from this testing useful for the widest possible population, data are plotted on graphs relating a full range of values for particular anthropometric dimensions with their operational effects (such as sitting eye height in inches versus over-the-nose external field of view in degrees).

68. An example AAAA graph is provided in figure 1. The data from this graph come from an external field of view assessment performed on a Navy jet trainer with an ejection seat that only moves in one direction along a rail. In this example, the lowest sightline obtainable for each subject looking straight ahead over-the-nose (0 deg azimuth) is plotted. As can be seen by the four vertical bands of raw data, four subjects were used. Two had small sitting height dimensions and two had large sitting height dimensions (a determination of specifically how "small" or "large" requires comparison with the aviator population's anthropometric data base). The lone datum at the 34.5 in. sitting height resulted from a data check performed by blocking the 33.5 in. sitting height subject with a 1 in. buttock block.

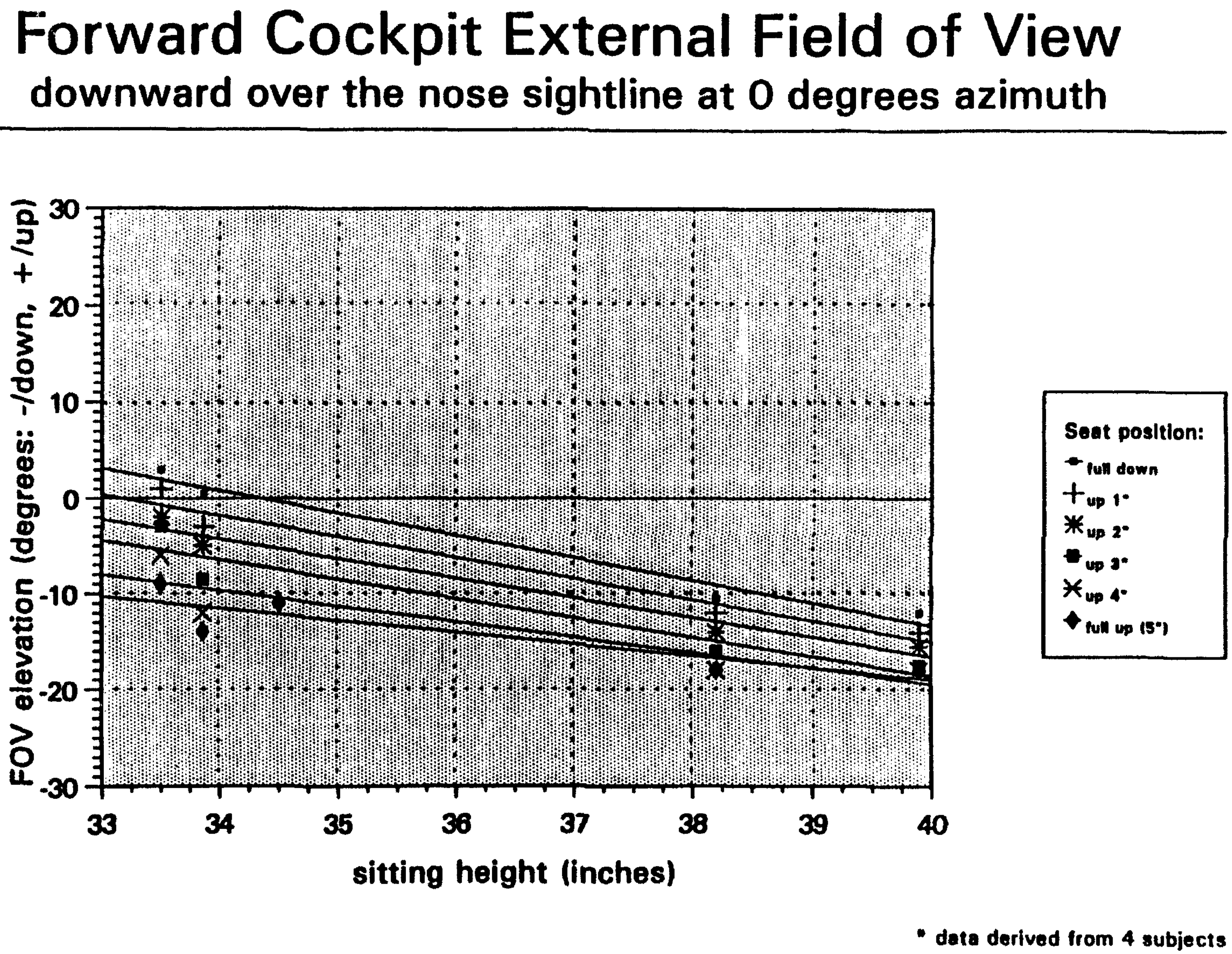

Figure 1
EXAMPLE GRAPH USING AAAA DATA

69. Since this graph represents the lowest sightline obtainable at each of six different seat positions (the full down seat position was later referenced to NSRP), the graph implies that the area below each line is not accessible to external field of view and that the area above each line is accessible to an external view. These areas can be shaded, hatched, or colored for easier interpretation, although that was not done here so the raw data would not be obscured. A visual inspection of the graphs shows that the regression lines are essentially parallel between seat positions, as is logical for seat position changes that are separated by equal increments (except for cases of unusual interactions from the cockpit perimeter). The lowest seat position is represented by the highest regression line because the aircraft's perimeter "rises" relative to the subject's eyes as the seat is lowered into the cockpit. The opposite is true for the full-up seat position.

70. By plotting the raw data and using appropriate regression equations, this graph now provides an estimate of downward external field of view restrictions at the straight ahead over-the-nose position for any sized subject (with respect to sitting eye height) at any seat position. For instance, the graph shows that a pilot with a 37.0 in. sitting height at the "seat up three inches" seat position had external field of view obstructed below 10.5 deg down.

71. In some cases, different AAAA graphs can be directly superimposed to expand the level of interpretation and better demonstrate interactions between different aspects of testing. For instance, upward external field of view could be directly incorporated into this example graph. These regression lines would then be interpreted opposite to the ones for downward field of view (areas above the lines would represent field of view obstructions and below would represent visible regions). Hence, total external field of view obtainable would be represented by the area between regression lines for each seat position.

72. Bivariate anthropometric relationships (such as the interactions between functional arm length and sitting acromial height for obtainable functional reach) require more detailed graphical methods since the data are essentially four-dimensional (functional arm length and sitting acromial height versus seat position and functional reach obtainable). These relationships are represented by dividing the data into two or three-dimensional relationships and graphing accordingly. The test measurement dimension (functional reach obtainable) can be deleted by calculating out the surplus or miss values to the "just acceptable" level. Continuing with the example, this results in graphs of functional arm length versus sitting acromial height at each predefined seat test position. The data and regression lines then represent the relationship between functional arm length and sitting acromial height such that the specified control(s) are just reached at that particular graph's seat position. This yields a set of graphs equal to the number of seat test positions. Include the method of calculating out the surplus or miss values with the final graphs.

73. An individual's measurements can be applied to these graphs to show if there is an optimum seat adjustment position available and what degree of accommodation the cockpit/crewstation provides for that individual at any desired seat position. Through effective design, there will theoretically be a seat position or range of seat positions where each individual will be able to perform all functions adequately. However, comparison between graphs will demonstrate the reality of the tradeoffs mentioned above and show important operational restrictions for each individual.

74. Anthropometric measurements from the general population can be compared to the AAAA graphs. This is useful for demonstrating contractual and specification compliance/noncompliance with accommodating a specified range of anthropometric values. For instance, an aircraft may be required to accommodate all people having anthropometric dimensions between the 3rd and 98th percentile values. The resulting graphs can also provide the minimum and maximum values of specified anthropometric dimensions that are needed to successfully operate the aircraft. This provides a general set of "rules" against which any individual or population range can be quickly compared for suitability in using a particular cockpit/crewstation.

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AIRCREW ANTHROPOMETRIC ACCOMMODATION ASSESSMENT PROCEDURES

GENERAL

75. The following sections deal with specific areas of AAAA. Methods, considerations, cautions, and contingencies are presented. An abbreviated, step-by-step version of these procedures is provided in appendix B for field use and review.

OVERHEAD CLEARANCE

76. Overhead clearance assessment determines the amount of clearance above and to the sides of the head. This is generally only an issue with larger subjects and is dependent upon sitting height and headwear dimensions.

77. As in all areas of testing, experienced aircrew are preferable subjects. They are best able to realistically simulate left and right head tilts for looking down or around the aircraft's nose, views over the sides, and head turns required to look aft for aircraft visual searches (especially important in fighter/attack aircraft).

78. Certain basic ideas apply to all iterations of this testing. At each predetermined seat position, situate the subject with shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and the head leveled in the Frankfort plane. The Frankfort plane (also known as the Frankfort horizontal) is an imaginary line connecting the superior (upper) surface of the ear's tragus (a cartilaginous flap located in the mid-forward part of the ear) to the infraorbital (lowest bony point on the anterior rim of the eye socket). For aircraft with canopies, fully close and lock the canopy into its flight position. For other aircraft, orient all overhead areas and controls in their operational flight positions.

79. If headwear is used in making measurements, it is important that key dimensions of the helmet and other equipment are measured. Determine the height and width that the helmet adds to the bare head so the same test results can be used even if future changes to headwear occur. Headwear sizing factors are then deducted from the original data and new sizing factors are added. Different measurements will be needed for different areas of the headwear. For instance, the top of a helmet may need to have measurements taken from the bare head to the helmet shell in addition to the top of a protruding visor knob. Note nearest locations and measuring points on the bare head for future reference.

80. When using helmets in a cockpit, it is prudent to tape thin, soft foam or rubber to the top of the helmet for reducing the possibility of canopy scratches. A slightly thicker foam pad on top is also helpful when an evaluator needs to stand outside of a clear canopy to determine helmet contact. The evaluator will watch for compression of the foam in determining the point of contact as the seat is raised.

81. Measuring the surplus overhead clearance can be difficult for some aircraft due to tight spaces and awkward access. If the cockpit or crewstation is open enough for the evaluator to have direct access to the subject during the evaluation, measurements are simplified. An appropriate inside-diameter caliper can be used. Also, some form of measurable material can be placed between the headwear

and overhead obstructions, and the material can be removed for measurement with a linear scale (such as a standard ruler or measuring tape). If a ruler is used directly, the measurer must be wary of parallax error.

82. Evaluators must be aware of geometric variances caused by seat repositioning. Head and seat movements will likely not be correlated linearly. For instance, a moving ejection seat alters the angular relationship between the seat bucket, headbox, and head. Also, the slope of a canopy or overhead panels will affect clearance measurements as the seat is moved through its range, especially for aircraft with reclined seatbacks or ejection rails.

83. Other relevant design characteristics need to be considered. For instance, in ejection seat aircraft with canopy piercers above the headbox, the headwear should not contact the canopy before the piercers are permitted to break through. The relative distances are measured perpendicular to the plane of the overhead canopy surface in the direction of ejection. An appropriate amount of piercer penetration is determined on a case-by-case basis. Spinal compression under ejection acceleration forces is an important factor but is beyond the scope of this report.

84. Considerations for expected head movements will need to be compared with volumetric criteria expressed through aircrew input or specifications. These requirements are frequently met by larger and side-by-side aircraft, but the space available is frequently marginal or inadequate in high performance aircraft with their correspondingly small cross sections. Guidance in this area is generally more realistic and specific from experienced aircrew, although the observations may be subjective. Their input is especially useful in considering the effects of negative-g situations, head turning to look aft, and turbulence or vibration effects on jostling the head around. A "safety factor" for a minimum amount of available head clearance is determined from these sources and compared to the results obtained from measuring absolute surplus clearances.

EXTERNAL FIELD OF VIEW

85. External field of view assessment relates aircrew anthropometry to up/down elevation sightlines available at different left/right azimuth locations. It concerns the full population under consideration, with the primary anthropometric dimension being sitting eye height. Smaller people may have problems in attaining sufficient downward vision (because of a glare shield or the perimeter of the aircraft, for example), whereas larger subjects may encounter problems in attaining unobstructed upward vision (because of a canopy bow or overhead control panel, for example).

86. Theoretically, aircraft designers have designed cockpits, crewstations, and adjoining structures to provide a balance between internal and external field of view. This is sometimes supposedly optimized at the DEP for meeting all contractual requirements. However, frequently all requirements are not met and/or aircrew sit at different seat positions. This compensates for desired anthropometric accommodation or for individual preferences and priorities (for instance, moving up to see a landing strip instead of lowering the seat to be aware of warning lights under the glare shield).

87. Measure downward and upward sightline elevation angles at various left/right azimuth angles. Before this is performed, however, define the coordinates relative to the aircraft. Zero degrees azimuth is defined as straight ahead (relative to the aircraft's centerline, fuselage, and/or flightpath) from the subject's eye

position, with negative degree values toward the left or port side and positive degree values toward the right or starboard side. Azimuth angles are measured by having the subject use an optical protractor. These measurements are independent of aircraft orientation on the ground. The aircraft will likely be level from side to side, even if it has a noseup or nosedown attitude. If there is an unusual list to either port or starboard due to uneven weight distribution across the aircraft, the optical protractor will need to either be set horizontal and compared to the aircraft waterline or directly lined up with the waterline angle, which differs from horizontal in the side to side direction.

88. Specific azimuth angles may be of interest for comparison to specification (see appendix C) or contractual requirements. Once on the aircraft, other azimuths may be of interest to demonstrate the effect of obstructions or to create a more complete range of data. If a specific azimuth and elevation position coincides with an aircraft hardpoint (such as an overhead compass or the juncture of the canopy bow and glare shield), note this for: 1) later comparison to cockpit/crewstation drawings, 2) overlap with internal field of view data, and 3) a better sense of what the data represent in the crewstation.

89. Defining a 0 deg plane for elevation angles (i.e., up and down sightlines) can be more difficult. Aircraft do not necessarily sit on the ground in the same attitude that would occur under normal flight. Aircraft assume different noseup/nosedown attitudes for different aspects of flight (such as "straight and level" flight, "noseup" glideslopes for aircraft carrier landings, and "nosedown" for helicopter forward movement). Aircraft orientation under straight and level cruise flight is a preferred starting point for determining a 0 deg "horizontal" plane.

90. To obtain a 0 deg elevation plane of reference, determine the desired aircraft attitude and reference marks on the aircraft that define or are parallel to the aircraft's waterline. This may be from an imaginary line defined between hardpoints on the aircraft, or it may be a panel on the aircraft that is designated as being parallel to the waterline plane. Compare the desired attitude and the waterline for any differences. If the desired attitude is not parallel to the normal aircraft waterline, then this difference is factored in. When at the aircraft for testing, determine the current orientation of the aircraft waterline (using the reference marks already obtained) as the aircraft sits relative to the earth. Take these measurements with the subject, any evaluators, and equipment on the aircraft since the extra weight can change a light aircraft's sitting position.

91. Once the waterline's orientation is determined, testing can be performed. For the sake of expediency, field of view measurements are taken in the field using an Abney level, which measures relative to the horizon. This is independent of the aircraft; however, some digital devices can directly include the offset factor for the aircraft orientation. The aircraft orientation and desired aircraft flight attitude are considered later by adding or subtracting the appropriate factor (calculated from this waterline orientation on the ground and the desired flight attitude deviations from the waterline plane). Taking this raw data decreases workload and the chance of errors in the field. The noseup/nosedown factor only applies to measurements taken in the forward direction. This factor becomes negligible for 90 deg azimuth side viewing and is reversed for aft viewing.

92. At each seat position, ensure that the subject's body is properly positioned in the seat and the head is leveled in the Frankfort plane. Take up and down sightline measurements at specified azimuth angles with the subject handling the Abney level and project personnel obtaining angle readings from the device. Note all field of view restrictions at each particular azimuth.

93. Test head positions other than head level. Although the level Frankfort plane position helps create repeatable eye locations that serve as a good baseline for comparison, head tilts and swivels provide useful information that increases realism beyond the relatively static head level position. Aircrew frequently need to move their head and eyes to see around an aircraft's external field of view obstructions.

94. Sideways and up or down head motions are defined from the standard Frankfort plane. This determines the ease of getting around obstructions or of increasing desired sightlines. The difficulty here lies in quantifying the head tilt, making it repeatable, and maintaining consistency between subjects. Chin up and chin down head tilts are defined by the angle that the Frankfort plane moves from the level position (such as ±20 deg, measured by a digital inclinometer or even the Abney level if used properly). This can also be established by a distance measurement of eye movement above or below the level Frankfort plane (such as ±1.2 in., measured by a ruler from the fixed plane), although this requires the ability to locate points in space and may be unacceptably vague. Sideways head motion is measured in the same way in its respective plane of movement.

95. Each method of observing head tilt requires close supervision by the evaluator. Head motions will not simply rotate around a single point due to curvature and bending in the spine. The subject may also inadvertently move other parts of the body, especially for a sideways head tilt. If extreme head tilts are combined with significant body motions (such as the subject bending to the side for maximum downward view over the side of the aircraft), repeatability and body position definition are difficult. However, general descriptions may be good enough to determine "maximum over the side field of view obtainable", "maximum forward field of view with head firmly back against the headrest to simulate a catapult or high-g situation", or "maximum aft field of view with full twisting of the torso permitted".

96. Aft field of view, especially with the harness or other restraints unlocked, is pertinent to sighting other aircraft and to evasion tactics. However, the contorted body positions needed for looking aft make measurements difficult and imprecise. To counter this, a large "banner" of angular markings calibrated and measured from a fixed point (such as DEP) can be suspended behind the entire aircraft. The banner needs to account for the distances to the fixed point and the relative geometry of the angular measurements being superimposed onto a planar banner. Obstructions from aircraft structures or the canopy and any movement restrictions will be accounted for when using this method. Due to the time-consuming nature of setting this up and ensuring that the markings are properly aligned, it is recommended that an alternate team of project personnel work on this while other testing occurs in the aircraft. This has been performed successfully before for a project needing detailed aft field of view data.

97. We also have the capability to present a full 360 deg field of view plot around a cockpit or crewstation from a desired point above the seat. The plots are made by the Field of View Evaluation Apparatus (FOVEA), which is controlled by an operator at a remote terminal. FOVEA provides detailed azimuth and elevation "maps"

of external field of view and is especially useful when an individual viewpoint is of interest (such as from DEP). However, FOVEA can take over an hour from each perspective point to map the field of view (after setup has been completed), and it also may be cumbersome to repeatedly match the eye positions of actual subjects to the location of the device. FOVEA plots may be too time- and labor-intensive for AAAA procedures (with their test cycles through multiple seat positions), but can be useful for detailed data at specific test positions.

98. Minimum acceptable external field of view can be obtained from military standards, design specifications, and especially aircrew input. Criteria will be dependent upon the type of aircraft, its mission, and what flight maneuvers are being performed.

INTERNAL FIELD OF VIEW

99. Internal field of view testing determines the degree of biocular visual access provided for controls and displays that need to be viewed along an unobstructed sightline. The primary anthropometric dimension of interest is sitting eye height. Internal field of view can affect the entire population depending upon aircraft layout. Larger subjects tend to have more distinct problems because of their higher view down onto glare shields, light assemblies, protruding panels, and control mechanisms. But, smaller subjects may be more likely to encounter visual obstructions from the yoke or throttle. Body segments (knees, for example) can create visual blockage for lower controls and displays (requiring notation of the relevant anthropometric dimensions and their effects). Flight gear and accompanying equipment can also obstruct lower and surrounding areas.

100. Many of the subject positioning procedures parallel those described in the External Field of View section, paragraphs 92 through 96. Normal subject body position, unusual body positions, monitoring of head position, and determination of appropriate, repeatable, and mission related head tilts are essentially handled the same.

101. In the case of internal field of view, head tilts can determine whether or not mild head motion allows the subject to compensate for an obstruction by seeing around it. This adds some reality to the rigid Frankfort plane baseline sitting position and defines the extent to which a particular layout is deficient. In fact, the Frankfort plane position is frequently unrealistic for this test since most people physically tilt their head down to look at controls and displays. This tilting should be allowed and encouraged, but coach the subject to not make unusual head or body motions. The extent to which the head or body needs to be moved to circumvent a visual obstruction is noted as a separate datum. This approach lacks the precision and repeatability of a more rigid Frankfort plane position, but it is nonetheless more realistic.

102. Head Up Display (HUD) evaluations are fairly complex given the variables of eye position up/down/forward/aft, the type of HUD, and any given HUD's particular optical characteristics. A thorough evaluation of a HUD requires an understanding of these topics and their interrelationships. Familiarization is strongly recommended if HUD evaluations are to be included in the overall aircraft testing. Because of their nature, HUD evaluations can be included in both internal and external field of view assessments.

103. At each seat position and at other eye locations besides those at a normal sitting position, notes are made from subject comments regarding what information is visible on the HUD and what is outside of the HUD's "porthole". Technical drawings of the HUD format being viewed are helpful in quickly sketching the visible information at each position and in providing an understandable record of the test session. Results include percentages of areas obscured and positions that hinder access to critical HUD information. For precise but time-consuming measurements, Aircrew Systems (SY72) has developed a capability to quantitatively define Instantaneous Field of View, Total Field of View, and Biocular Instantaneous Field of View through a photographic process.

104. Bringing multiple photocopies of a detailed cockpit/crewstation layout diagram helps considerably in taking quick notes. Areas of obstruction are drawn with hatch marks, and sources of obstructions are pointed out. These diagrams are then combined with the external field of view notes to combine relationships to aircraft hardpoints.

105. Ensure that a thorough survey of the cockpit or crewstation is performed by the subject, including consoles, placards, and hidden controls. Information to note during the tests includes: the object obstructed (for example, "Accelerometer"), percentage of the object's total area that is obstructed from view (for example, "upper 40%"), specific description of the object's area obstructed (for example, "imaginary line between numerals 3 and 9 on the indicator face and everything above that line"), and cause of obstruction (for example, "aft upper edge of glare shield"). Include the ease with which the subject can circumvent the obstruction and a sketch of the obstructed area. With the exception of the sketches on cockpit/crewstation layout diagrams, keep much of this information in tabular form for easy reference.

FUNCTIONAL ARM REACH

106. Functional arm reach testing determines the degree to which a person can properly, efficiently, and comfortably reach and actuate cockpit/crewstation hand control mechanisms. Reach capability is determined for the flight stick/yoke, throttle, input devices, and all primary and secondary buttons, switches, handles, levers, etc.

107. The anthropometric dimensions of primary concern are functional arm reach and sitting acromial height. Dimensions of secondary concern that may need consideration on certain aircraft include downward vertical reach, upward vertical reach, bideltoid diameter, shoulder-elbow length, forearm-hand length, and hand dimensions such as hand length. Functional arm reach is generally only a concern for subjects with smaller functional arm lengths. The worst level of accommodation frequently occurs for those with small functional arm reach and large sitting acromial height, although this is dependent upon cockpit/crewstation layout (for instance, helicopters with overhead panels favor large sitting acromial heights). For this reason, subject selection favors small functional arm reaches and a broad range of sitting acromial heights.

108. Always consider operational requirements and flight situations during the course of testing. Make reach estimates from one or both hands that would actuate a particular control. However, temper this by the effects of shoulder restraints and the needs for a specific hand to perform a specific action. For instance, right-handed yokes/flight sticks favor right hand control; therefore, controls to the right of the crewstation centerline may realistically be performed by the left

hand. However, this is constrained by the awkwardness of cross-crewstation movements and by limited mobility from restraint systems. When time permits, it is useful to obtain reach measurement data from both arms to account for individual preferences and unusual situations. Editing out unrealistic data can be done after test sessions are finished. As is generally the case, it is better to perform measurements on too many controls than too few.

109. All control mechanisms in a cockpit/crewstation are eligible for evaluation, including all primary and emergency controls, throttle, circuit breakers, flight stick/yoke (at neutral, full forward, full left, and full forward-left positions), utility lights, aft sections of a console, etc. Cockpit/crewstation layout diagrams, similar to those used in the internal field of view testing, are useful in taking notes and defining areas of interest. If a mechanism has a large range of motion (for example, a throttle, yoke, or emergency landing gear handle), the full range should be quantified through distance, plane of motion, and angular motion. This facilitates making observations about miss distances to certain controls and the resulting effects on accomplishing a full range of control motions. For instance, a subject may be able to push a flight stick through only X% of its leftward motion with a functional arm reach of Y inches. Balance this information against actual mission requirements (for example, a flight stick may never realistically be pushed full forward-left). If applicable, determine the point beyond which a control's movement will add no additional effect.

110. Obtain direct reach miss distances by having the subject attempt to actuate the control being evaluated and measuring from the control interface point (for example, center of a button, palm area of a throttle, or inside of a handle) to the hand's interface point (such as an index finger tip, center of the base of the palm, or inside of fingers in a loose "fist" configuration). Describe the overall hand/palm/finger positions used for each control for repeatability between subjects and for future testing.

111. Surplus distances (i.e., where a subject has excess reach capability and could essentially push or reach further through the control if the design allowed it) are more difficult to accurately determine. The problem stems from the fact that hands and measuring devices cannot be thrust into and through hard cockpit controls. Since surplus distances are important for interpolating data and estimating minimum reach requirements, it is nonetheless necessary to measure surplus distances encountered during testing.

112. Surplus distances, as well as miss distances, are measured from a specified area on the forearm instead of measuring directly to the hand's interface point. The sleeves of flight gear will need to be rolled up to the elbows for this method. Thin ink marks are then spaced evenly around the forearm approximately 5 in. above the wrist. This acts as a reference band.

113. Before a subject attempts to actuate a close control, the subject outstretches the arm and hand into a position similar to that used on the particular control being evaluated. The subject then simulates the appropriate grasping, pulling, pushing, or rotating position of the hand. A measurement is taken from the band on the forearm to the hand's interface point. This will provide the normal interface distance from the forearm band. The subject then attempts to actuate the control. Since the hand's interface will go beyond the actual control surface, the hand is swung down at the wrist and the arm is fully extended for the position that the subject is simulating. This enables the arm to maintain its outstretched position without the need for retracting it back to accommodate for an outstretched hand.

For controls that still hit the arm at or above the wrist, the arm will need to be placed alongside the control. However, the control is likely close enough to not be an accommodation issue and can be eliminated from the testing cycle. Otherwise, a subject with a shorter functional arm length will need to be used.

114. Surplus distance will equal the forearm band/hand interface distance minus the forearm band/control interface distance. If desired, miss distances can be determined by this method except that the distance will be negative. Group together controls that are actuated by essentially the same hand positions so that the same forearm band/hand interface distances can be used for consecutive measurements. A similar alternative is to go through all of the controls, matching each control to the appropriate predefined, premeasured forearm band/hand interface distance afterwards.

115. There are important differences between functional arm reach measurements in anthropometric data bases and functional arm reach measurements here. For instance, if the Anthropometry of Naval Aviators-1964 (NAEC-ACEL-533) is used to determine subject percentiles in the aviator population, be aware that this study measured functional reach out to the end of the touching thumb and index finger with the thumb straight. This tip is not an appropriate interface for many controls. For instance, the throttle is gripped and thrust forward by the palm and the flight stick is grasped around by all five digits. This does not mean that data base functional reach measurements are disregarded, but it is a caveat that this specified distance and position is not the actual one used in an operational aircraft. Therefore, these static, well-defined positions are used for general comparisons between subjects and population data bases, but are not used as actual test positions or measurements if others are more realistic.

116. Evaluate functional arm reach from three different subject seating positions, based on the Zones from MIL-STD-1333B. Zones 1, 2, and 3 frequently serve more as standardized references to general body positions than to any actual mission relationship. Although these Zones only serve as generalized positioning for various aspects of flight, they do well in serving as a somewhat defined and repeatable set of subject positions. They can be used at any seat position, not just limited to a position approximating DEP (as specified in MIL-STD-1333B). They can also be used between different subjects and different test sessions for continuity and comparability. None of these positions should be rigid or pushed to the point of being overly uncomfortable for the subject.

117. Perform all Zone measurements in increasing zone number at each seat position. Controls that do not present a reach problem in Zone 1 may not be worth the effort of investigating in Zones 2 or 3. Likewise, controls that are acceptable in Zone 2 will definitely be within acceptable reach in Zone 3. Zone 3 measurements should emphasize those controls not reachable in Zones 1 and 2. Determine the need for extra data on an individual basis. Evaluate all controls together under each Zone position to help maintain similar shoulder positions between measurements. Repeatable shoulder positions significantly help in obtaining repeatable data and in making valid comparisons between different controls and different seat positions. This is most critical for Zone 1; Zone 2 is artificially constrained by the restraint system (although similar harness tension and positioning needs to be maintained) and Zone 3 has much more leeway and variability.

118. Some modern restraint systems may cause difficulty in simulating Zone 2 due to a lack of a stable locking mechanism. Some of these systems utilize a rapid deceleration-activated inertia reel that permits free movement of the subject against the harness in a static environment. It is necessary to simulate a Zone 2 reach in this situation. However, a Zone 2 assessment may provide only vague data and therefore not provide solid relationships to operational constraints.

119. MIL-STD-203 and MIL-STD-250 assign certain controls to minimum reach zones, but these will likely need to be modified for each aircraft. Some controls need to be accessible from a more stringent zone, and others may allow more leeway due to differences in mission priorities. Zone 1 control lists can be unrealistically strict, especially for aircraft with moveable automatic locking inertia reels. Zone 2 may be acceptable in cases designated for a Zone 1 requirement. Aircrew consultation and NATOPS information are needed to determine this, although contractual obligations and specifications/standards should be factored in.

FUNCTIONAL LEG REACH

120. Functional leg reach assessment relates leg dimensions to a corresponding degree of foot control movement and operability. Anthropometric dimensions of interest include functional leg length, buttock-knee length, sitting knee height, and boot size. Functional leg length is the primary dimension since legs approximate a straight position when attempting fully extended reach. However, buttock-knee length and sitting knee height are important components, especially if there is significant knee flexion due to the relative location of foot controls and the forward seat edge. There can be significant variability in functional leg reach assessment data because of the relative relationships between portions of the leg, knee flexion, and thigh gap to the seat. The evaluator's priorities will depend upon each cockpit/crewstation layout. Functional leg reach is generally only a concern for smaller subjects; related problems for large subjects will usually result from extremely confining cockpit/crewstation space and will overlap with leg clearance problems (see Leg Clearance section, paragraphs 130 through 137).

121. Before testing begins, measure the foot control adjustment range and note positions in number of notches (with the distance between notches also measured and noted) or by a linear scale. Position the subject with buttocks back in the seat and upper torso erect but comfortable, not rigid. Plant the subject's footwear solidly on the pedal or control and properly connect toe guards, heel catches, and leg restraints and use as intended. Adjust the yaw pedal carriage and/or other foot mechanisms to their full aft position closest to the subject. This position will theoretically provide the least reach problem for a small subject.

122. While maintaining a comfortable sitting position, have the subject attempt to actuate the foot controls through their full range of motion. For yaw pedals with brakes, have the pedals pushed through their full left and right forward throw. If the subject can accomplish this with full knee extension but no straining against the restraints and no forward movement of the hips or torso, have the subject attempt to rotate the toe brakes at the full throw positions. Although this is an unlikely rudder/brake combination, it does represent the functional leg reach worst case scenario.

123. Perform actions that put foot controls through their full range of motion at each predefined seat position. Generally, upward seat adjustments move the leg away from lower foot controls and therefore require a longer functional leg length (and vice versa). A reclined angle of seat motion can also be a factor.

124. If all of the foot control movements are performed successfully at every seat position, then that subject's particular dimensions are considered acceptable for full foot control operation. Then obtain a subject with smaller leg dimensions to determine minimum leg dimensions and/or miss distances. Estimating surplus leg reach distance is difficult because of the leg's variable geometry around the knee and the fact that the plane of the subject's legs will not directly coincide with the plane of foot control movement and adjustability. In other words, the subject's legs will likely be pointed down at the controls with the added variables of knee flexion, cockpit/crewstation layout, and seat constraints. Also, the plane of control motion will likely extend to a level below the hips and seat.

125. From the successfully accommodated subjects, however, useful data can be derived by moving the foot controls forward (away from the subject) at repeated increments until the subject can no longer perform all of the desired control movements. This describes the amount of adjustability that can be utilized by aircrew with specified dimensions. It also overlaps with leg clearance data (see paragraphs 130 through 137). However, place emphasis on the minimum functional leg reach requirements at the foot control's most favorable position (generally adjusted full aft for smaller subjects).

126. If a subject cannot perform all of these movements due to reach limitations, determine miss distances and control movement restrictions. If the cockpit/crewstation layout is essentially symmetrical, then only one leg will need to be tested. Choose the side based on convenience and access for the evaluators. Due to common differences in leg lengths on a person, both legs should be measured before testing so that the evaluated leg will be defined by valid measurements.

127. If leg reach comes up short for a particular foot control movement (such as full forward right throw), measure the miss distance from the relevant location on the pedal or control to the respective location on the bottom of the subject's boot. This requires assistance from the evaluator in pushing the pedal beyond the range of the subject's boot to obtain the miss distance space. A good repeatable location is obtained from the center of the boot's heel to the respective control location. The heel's motion is less variable than the foot's extremities because of the foot's rotation around the ankle area (nearest to the heel). However, some controls require measurement from the ball of the foot (such as for toe brake rotation or switch actuation).

128. If it is not possible for evaluators or subjects to effectively move foot controls through their full motion without compromising subject body positioning, then an estimate is made. First measure the control's entire travel range (possibly by using a larger subject). Then measure the smaller subject's limited range of motion on the control and subtract this from the overall value. Remember the caveats stated in paragraph 124. Error can be diminished by accounting for the geometric relationships between leg dimensions, hip sockets, and the foot control's location, range of motion, and plane of motion. Taking several measurements from a hardpoint on the forward edge of the seat helps in triangulating these locations and ranges of motion.

129. Excessive interpolation and extrapolation of these data can create erroneous results because of the widely variable combinations that are possible between seat position, foot control positions, foot control range of motion, foot control plane of motion, varying anthropometric measurements, geometric relationships between anthropometric dimensions, and thigh gap. To help decrease the need for interpolation and extrapolation of data, functional leg reach assessment is a good

candidate for blocking (see Artificial Anthropometric Extrapolation section, paragraphs 32 through 39). Although this is a physical form of extrapolation, it does provide a wider range of directly measurable reach assessments with a limited number of subjects. Blocking techniques are used to artificially increase functional leg length, buttock-knee length, and sitting knee height.

LEG CLEARANCE

130. Leg clearance testing relates leg dimensions to the amount of clearance between the leg and hardpoints in the cockpit/crewstation. In other words, leg clearance assessment determines the amount of free space (if any) between a subject's leg and any projections or devices in the aircraft that would contact the leg while in anticipated sitting positions. The key anthropometric dimensions are functional leg length, buttock-leg length, sitting knee height, boot size, thigh circumference, and lower thigh circumference.

131. Leg clearance is generally only an issue with large subjects. However, small subjects may also be a concern if a forward/aft adjustable seat needs to be moved forward (to increase functional arm and leg reach) and this results in thigh obstruction to the flight stick range of motion or lower ejection handle access. Also, small but bulky subjects may encounter similar problems in other seats.

132. Due to the large number of relevant anthropometric dimensions for this aspect of testing, evaluators need to decide on which dimensions are important to their testing. Boot size, thigh circumference, and lower thigh circumference can frequently be spot-checked while testing the other dimensions. If a potential problem is encountered with these dimensions, they can then be looked into methodically. Their effects can be fairly constant across seat positions (for example, a size 13 boot may not fit within yaw pedal toe guards or within the confines of a small yaw pedal well, and this problem will likely not change significantly in relation to seat position).

133. Basing subject selection and test approaches upon buttock-knee length and sitting knee height combinations provides a more complete picture of leg clearance than just using overall functional leg length as a primary dimension. For instance, an "average" functional leg length may have components of a large buttock-knee length and a small sitting knee height. The large buttock-knee length may project into the lower MIP, yet the functional leg length measurement would not necessarily indicate this since a different subject with the same overall leg length may not experience contact problems. Also, never simplify a leg's geometry by assuming that buttock-knee length plus sitting knee height equals functional leg length.

134. Using two dimensions instead of one multiplies the potential variables and significantly increases the number of subjects needed. Base subject selection and number of subjects upon a range of combinations of two dimensions instead of a range of just one dimension. Also, it may be difficult to find subjects with the unusual, "disproportionate" combinations of buttock-knee length and sitting knee height that would be helpful in graphing results and making conclusions. If a lack of time and/or subjects requires it, functional leg length alone may cautiously be used as the primary anthropometric dimension.

135. At each step through the cycle of seat positions, the subject adjusts yaw pedals and other foot controls to a comfortable position that minimizes thigh gap to the seat and allows full throw and rotation of the pedals or other controls. Problems concerning leg reach are addressed in the preceding section (see

paragraphs 120 through 129). Forward/aft (or up/down, if applicable) foot control adjustments should be located by the number of notches or by a scale (a ruler or markings on masking tape) located relative to the mechanism's full range of adjustability.

136. For yaw pedal controls, make observations at a neutral position, pedals full left, pedals full right, and brakes rotated full forward. Other types of foot controls require that the extremes of control motions be assessed. At each foot control position, measure and note contact points. This frequently occurs around the knee and upper shin against the MIP, instrument faces, levers and switches, etc. Take measurements of the smallest clearance distances from the near point on the leg to the near hardpoint in the aircraft. Exert slight pressure on the flight suit to get the calipers or linear scale down near the level of the subject's skin. Make descriptive comments concerning the location and relationship of these two points. Note any light contact, snagging, or interference with flight gear.

137. Leg clearance assessment is a good candidate for blocking (see Artificial Anthropometric Extrapolation section, paragraphs 32 through 39). Blocking reduces the number of subjects needed and the overall testing time. Also, it performs well in the two anthropometric dimensions of primary concern: buttock-knee length and sitting knee height. Blocking is especially useful for obtaining more data from subjects who do not encounter any leg contact problems during their test session.

THIGH GAP

138. Thigh gap assessment relates aircrew leg dimensions to clearance between the lower thigh and the seat encountered when foot controls are actuated throughout their range of motion. The primary anthropometric dimensions of interest are functional leg length, buttock-knee length, sitting knee height, thigh circumference, and lower thigh circumference. Thigh gap is usually only a concern for larger subjects in ejection seat aircraft. Measurements can be taken for comparison purposes against the injury records of other ejection aircraft to determine if thigh gap may be excessive. Excessive thigh gap may result in injury to the thigh or femur due to "thigh slap" as the seat accelerates out of the aircraft in an ejection. This assessment also provides a general measure of sitting position comfort that helps substantiate subjective aircrew complaints about fatiguing or confining foot control/seat relationships.

139. The key to obtaining useful thigh gap data is in the definition and use of the same measurement technique across all aircraft being compared. The simplest and most direct method is to measure the distance from the hard seat pan edge (not to the cushion) to the closest point on the underside of the thigh perpendicular to the femur. Cushion compression needs to be compensated for on an individual basis. Place slight pressure on the flight gear to get the caliper or linear scale near the level of the subject's skin.

140. Variability between subjects is a factor when determining the foot control position from which to take measurements. Position adjustable yaw pedal carriages such that the subject could comfortably sit for extended periods of time while maintaining the ability to actuate the foot controls throughout the full range of motion. This position will vary from subject to subject, but it is measured and noted by number of notches and/or by a linear scale. Using actual aircrew as subjects is beneficial in obtaining realistic carriage positions.

141. Take measurements throughout the full range of foot control motion, similar to the positioning used in determining functional leg reach (see paragraphs 122 and 123). For yaw pedals, measurements should be taken with pedals at neutral, full forward throw, and with any brake rotation at full forward throw.

142. Relate thigh gap data to each subject's functional leg length, buttock-knee length, and sitting knee height. Seat position and foot control position are factors controlled by the test session. Since the thigh has a great deal of pliability before it compresses against the femur, the potential injury relationship between measurements and actual ejection thigh slap varies with thigh and lower thigh circumferences as well as undefined differences in subject musculature and bone structure. This uncertainty is partially countered by using the same set of subjects on all aircraft to be compared. This minimizes anomalies between subjects and allows the data to at least be viewed in relative, if not absolute, terms. Until thigh gap and ejection-related injuries are more thoroughly studied and correlated, these measurements are taken for informational and comparison purposes only.

EJECTION CLEARANCE

143. Ejection clearance testing defines the clearances upon ejection between aircraft hardpoints and aircrew with specified anthropometric dimensions. Ejection clearance is generally only a concern for larger subjects. The primary anthropometric dimensions of interest include functional leg length, buttock-knee length, sitting knee height, boot size, and bideltoid diameter.

144. Ejection clearance procedures have been generally vague and undefined in past attempts at anthropometric accommodation assessment techniques. This is predominantly due to a lack of research on relating the dynamic effects of ejection upon a human body to static evaluations. Submarining (where the body is forced down and forward by the high-g forces encountered under initial ejection boost loads) requires further research. Downward and forward components to add to static ground test sessions with the seat either normally positioned in an aircraft or undergoing a full seat pull need to be determined. Research should consider submarining components to add with subjects in both a normally positioned seat and a full seat pull. This is a potentially complex task considering the dynamic effects that occur between the knees, thighs moving down onto the seat, feet swinging back, knees and forward tips of the feet protruding out along the ejection path, impact forces, leg restraints, and torso restraints. Recommendations from specifications and previous studies are generally vague and disconnected.

145. There are numerous straightforward procedures aimed at assessing ejection clearance. Most are variations on raising the seat as high as possible and forming a line parallel to the ejection rail through the forward-most part of each knee. Then check for obstructions across the plane formed by the lines from both knees. A flat board or several yardsticks usually suffice. This procedure is used if it is considered sufficient for the evaluator's purposes. Buttock-knee length is the primary anthropometric dimension of interest. Effects from sitting knee height, boot size, and bideltoid diameter are also observed by placing similar lines parallel to the ejection rail against the subject's boot tips and lateral shoulder extremities.

146. The dynamic environment of seat ejections actually requires the minimum of a full seat pull beyond the normal adjustment range of the seat. The seat may not need to be pulled completely off of the rail, however. Trajectory paths of feet and knees are best simulated by a seat pull. Even when the seat is adjusted to its full up position, this generally does not allow a large subject to fully compress the thigh against the seat and let the feet swing freely. Also, a seat pull will permit the addition of submarining effects in the event that they are ever effectively researched and quantified.

147. Seat pulls are performed with the overhead canopy either removed or fully opened. Therefore, potential obstructions in the canopy structure are not observed. This requires a separate evaluation with the seat adjusted normally to its full up position and the canopy closed. If needed, measurements are taken in conjunction with - and in a similar fashion to - those used in assessing overhead clearance (see paragraphs 76 through 84). Incorporate the effects of submarining and ejection rail angle into observations.

OTHER AREAS FOR ASSESSMENT

148. Although the most prevalent areas of anthropometric accommodation assessment are already discussed, there may be other areas of concern for a particular aircraft. These are briefly mentioned here. They are adapted to test sessions using the general philosophy and cautions of the methods already described. Some examples of other anthropometric dimensions that may have an impact on accommodation include:

a. Bideltoid diameter (can be a factor in close canopy rails or structures protruding into the cockpit/crewstation).

b. Aspects of hand size (related to palm fit and curl around throttle, fit on yoke, and access to switches/buttons/levers).

c. Waist depth (can degrade flight stick range of motion or hinder access to ejection handle).

d. Thigh circumference (can degrade flight stick range of motion, hinder access to ejection handles, and/or interfere with flight gear and other attached equipment).

e. Sitting hip breadth, buttock circumference, and sitting buttock circumference (affects fit into the "bucket" of seat and clearances with survival gear and fittings).

CONCLUSIONS

149. Aircrew Anthropometric Accommodation Assessment defines repeatable techniques for evaluating an aircraft's level of anthropometric accommodation for pilots/aircrew. Results determine the relationships between the full range of anthropometric values and the level of "fit" for a number of important areas. With careful attention to the cautions inherent in anthropometric studies and the variability of subjects, these procedures produce a useful overall picture of the ranges and limitations in an aircraft's anthropometric accommodation.

150. Benefits of this Procedural Guide include:

a. Standardization of procedures for Aircrew Anthropometric Accommodation Assessment.

b. Establishment of Aircraft Anthropometric Restriction Codes.

c. Reduction or elimination of fit checks.

d. Guide Student Naval Aviators into appropriate pipelines.

e. Determination of contractor compliance with design requirements.

f. Identification of deficiencies in the crewstation layout of mockups and aircraft undergoing development or upgrade.

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REFERENCES

1. "Anthropometric Accommodation in Naval Aircraft", NAVAIRINST 3710.9B, of 3 Mar 1987.

2. "Anthropometry of Naval Aviators-1964", NAEC-ACEL-533, by Edmund C. Gifford, Joseph R. Provost, and John Lazo; Naval Air Engineering Center, Philadelphia, PA, of 8 Oct 1965.

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BLANK FORMS

ANTHROPOMETRIC DIMENSIONS

Standardized measurement technique: ____________________
(Deviations from the above technique for individual morphological descriptors should be noted and attached to this sheet with origin, termination, and explicit body positioning information)
Number of measurements taken per dimension: __________ Averaged? __________
Measurer(s): ____________________
Measurementdevices: ____________________
Date(s): ____________________
Notes: ____________________

(lengths are in inches and weights are in pounds unless noted otherwise)

sex				
age				
race				
stature				
weight				
sitting height				
sitting eye height				
sitting acromial height				
functional arm reach				
hand ____________				
functional leg length				
buttock-knee length				
sitting knee height				
bideltoid breadth				
sitting hip breadth				
thigh circumference				
lower thigh circumference				
boot size				

EQUIPMENT CHECKLIST

EQUIPMENT	TAKEN TO AIRCRAFT?	RETRIEVED FROM AIRCRAFT?
forms, diagrams, documents		
clipboard(s), pen(s), paper		
calculator		
Abney level		
optical protractor		
digital inclinometer		
inside diameter caliper		
flexible metal measuring tape		
1 foot ruler		
yardsticks (2)		
sections of foam (#:______)		
duct tape		
masking tape		
blocking pads (#:______)		
video camera		
tripod		
video tapes (#:______)		

OVERHEAD CLEARANCE

Aircraft:____________ BuNo:____________ Configuration:____________________

Crewstation:____________ Seat type:____________ Seatback/rail angle:__________

Date:____________ Measurer:_____________________ Recorder:______________

Subject:______________________________ Stature:____________ Weight:__________

Notes/comments:____

____

____

Sitting height:__________ Headwear, dimensions:___________________________

(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/forward -/aft	RESTRAINT CONDITION/ BODY POSITION	CLEARANCE (in.)	CLEARANCE MEASURED BETWEEN WHICH POINTS?	NOTES

EXTERNAL FIELD OF VIEW

Aircraft:____________ BuNo:____________ Configuration:____________________
Crewstation:____________ Seat type:____________ Seatback/rail angle:____________
Date:____________ Measurer:____________________ Recorder:____________________
Subject:______________________________ Stature:____________ Weight:____________
Notes/comments:____

Sitting eye height:____________ Sitting height:____________
(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/forward -/aft	RESTRAINT CONDITION/ BODY POSITION	AZIMUTH +/right -/left	ELEVATION +/up -/down	NOTES

INTERNAL FIELD OF VIEW

Aircraft:____________ BuNo:____________ Configuration:____________
Crewstation:____________ Seat type:____________ Seatback/rail angle:____________
Date:____________ Measurer:____________ Recorder:____________
Subject:____________ Stature:____________ Weight:____________
Notes/comments:____________

Sitting eye height:____________ Sitting height:____________
(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/forward -/aft	RESTRAINT CONDITION/ BODY POSITION	INSTRUMENT, DISPLAY, AREA, ETC.	PERCENTAGE OBSTRUCTED	AREA OBSTRUCTED

FUNCTIONAL ARM REACH

Aircraft:__________ BuNo:__________ Configuration:__________________
Crewstation:__________ Seat type:__________ Seatback/rail angle:__________
Date:__________ Measurer:__________________ Recorder:__________________
Subject:__________________________ Stature:__________ Weight:__________
Notes/comments:____

Functional arm reach:__________ Vertical downward reach:__________
Sitting acromial height:__________ Vertical upward reach:__________
(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/fwd -/aft	RESTRAINT CONDITION/ BODY POSITION	CONTROL/ INTERFACE	BAND/ HAND DIST. (in.)	BAND/ CONTROL DIST. (in.)	REACH +/surplus -/miss (in.)

FUNCTIONAL LEG REACH

Aircraft:________ BuNo:________ Configuration:________
Crewstation:________ Seat type:________ Seatback/rail angle:________
Date:________ Measurer:________ Recorder:________
Subject:________ Stature:________ Weight:________
Notes/comments:________

Functional leg length:________ Boot size:________
Buttock-knee length:________ Sitting knee height:________
(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/forward -/aft	RESTRAINT CONDITION/ BODY POSITION	CONTROL/ ITEM	TYPE OF MOVEMENT/ LEG POSITION	REACH +/surplus -/miss (in.)

LEG CLEARANCE AND THIGH GAP

Aircraft:__________ BuNo:__________ Configuration:__________

Crewstation:__________ Seat type:__________ Seatback/rail angle:__________

Date:__________ Measurer:__________ Recorder:__________

Subject:__________ Stature:__________ Weight:__________

Notes/comments:__________

Functional leg length:__________ Boot size:__________

Buttock-knee length:__________ Sitting knee height:__________

(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/forward -/aft	RESTRAINT/ BODY/LEG/ CONTROL POSITIONS	CLEARANCE MEASURED BETWEEN WHICH POINTS?	CLEARANCE (in.)	THIGH GAP (in.)

EJECTION CLEARANCE

Aircraft:____________ BuNo:____________ Configuration:________________________
Crewstation:____________ Seat type:____________ Seatback/rail angle:__________
Date:____________ Measurer:____________________ Recorder:____________________
Subject:______________________________ Stature:____________ Weight:____________
Notes/comments:____

Functional leg length:_____________ Boot size:_____________
Buttock-knee length:_____________ Sitting knee height:_____________
(seat positions are relative to NSRP or other defined, repeatable location)

SEAT POSITION +/up -/down	SEAT POSITION +/forward -/aft	RESTRAINT CONDITION/ BODY POSITION	SUBMARINE/ EJECTION EFFECTS	CLEARANCE MEASURED BETWEEN WHICH POINTS?	CLEARANCE (in.)

QUICK REFERENCE/SUMMARY OF PROCEDURES

Quick Reference/Summary of Procedures for
Aircrew Anthropometric Accommodation Assessment

Subject Selection

Make subject selections with emphasis on the following four generic descriptions:
a) short/thin
b) short/heavy
c) tall/thin
d) tall/heavy

Use middle range subjects if a sufficient number of these extreme cases are already represented.

Experienced aircrew are preferable subjects due to familiarity with aircraft and operational/mission requirements.

Clothing/Gear

Provide and fit all subjects with properly sized clothing and flight gear as defined by the NATOPS or through Government Furnished Equipment (GFE). Represent "worst case" scenarios, including winter flight gear, exposure suits, and Chemical/Biological/Radiological (CBR) ensembles.

Handling Subjects

Be aware of:
a) Reluctant subjects making disinterested and/or unspecific assessments and inputs.
b) Eager subjects stretching beyond the points of acceptable comfort or making rigid assessments/criticisms that may be easily worked around in a real flight situation.

Perform as follows:
a) Have professional dress and behavior.
b) Show pleasant and respectful demeanor.
c) Provide an informative briefing before testing.
d) Be vigilant to changes in subject behavior and unintended or gradual shifts in body position.
e) Make firm, confident touches to subject's body when making measurements (precede measurements to potentially sensitive areas with a warning).

Anthropometric Measurements

Anthropometric measurements on subjects are to be performed (or at least supervised) by an experienced anthropometrist, aviation medicine/physiology technician, or aviation physiologist. Use current Navy Aerospace Medical Institute (NAMI) measurement techniques.

The following is a list of general information and anthropometric dimensions to acquire from every subject:

name
sex
age

race
stature
weight
sitting height
sitting eye height
sitting acromial height
functional arm reach
vertical downward reach
vertical upward reach
functional leg length
buttock-knee length
sitting knee height
bideltoid breadth
sitting hip breadth
thigh circumference
lower thigh circumference
boot size
pertinent hand dimensions (length, breadth, etc.)
(as needed: flight gear dimensions)

Defining Aircraft Seat Information

1) Determine Neutral Seat Reference Point (NSRP) from markings on the seat and contractor diagrams/descriptions. This point serves as a repeatable zero point from which seat movements occur in a positive (up/forward) or negative direction (down/aft).

2) Quantify the geometric relationships between the seat's different directions of movement/adjustability. Note up/down planes of movement by angle with respect to a level aircraft (such as along the ejection rail for ejection seat aircraft). Note forward/aft movement likewise.

3) In each of the planes of movement, define the full range of travel in inches or degrees. Measure full up/down and forward/aft movement ranges in +/- inches from NSRP. If there is swivel and/or tilt motion, measure it in angular degrees from a specified reference to the aircraft orientation (negative degrees to the left or back and positive degrees to the right or front). Also note other information such as rail angle and a three-dimensional description of the seat's orientation.

4) In each of these directions of movement/adjustability, identify and measure the number and location of permissible seat positions. For seats with continuous movements (such as motorized seats moving along a rail), this is not an issue. For seats with specific notched positions, measure the total number of positions and the distances between successive positions in inches or degrees throughout the seat's full range of movements.

5) Make sketches depicting the orientation and plane of movements, the full +/- range from NSRP, and the locations and relative distances of any notched seat positions.

Seat Related Procedures

The aircraft's seat acts as the one common point that connects all of the accommodation tests to one another. All AAAA tests are performed in a specified order from an individual seat position. When this iteration of all tests is completed, the seat is moved to the next position and all of the procedures are repeated. This process is iterated throughout the full range of seat travel at each predetermined seat position.

1) Determine a consistent separation distance between seat positions from the information concerning full range of seat movements (above).

a) For continuously adjustable seats, make test positions every inch for the full range of all movements, with a minimum of four equally spaced test positions.

b) For seats with notched positions, use the notches as test points.

2) Measure these test positions from NSRP.

3) Locate hardpoints on the seat (bolts, mechanisms, or such) which move across crewstation hardpoints (ejection rail, row of notches, crewstation floor, area of rotation, or such). These hardpoints define the movement away from NSRP throughout a particular direction (such as up, down, forward, or aft) by their relative translation across each other.

4) Note the +/- distances or angles from NSRP on lengths of masking tape applied to the nonmoving crewstation hardpoints. Arrange these masking tape scales so that a seat's position is located when it is moved along any axis or angle of rotation. Seat positions are then determined by observing each seat "pointer" moving across the tape as the seat is moved to other test positions.

5) From these masking tape scales, repeatedly locate test positions. Note seat positions in an x-y format (with the x-value representing the +/- forward/aft position, if needed, and the y value representing the +/- up/down position). Swivel and tilt measurements are noted as needed. Data blocks for seat position information are included on the blank forms in appendix A.

Artificial Anthropometric Extrapolation ("Blocking")

Artificial extrapolation of a subject's anthropometric dimensions, generally referred to as "blocking", increases the amount of data obtainable from a limited number of subjects. In effect, certain dimensions are artificially lengthened to create a "new" subject with a new set of dimensions.

Blocking under the boot:

1) Boot blocks increase sitting knee height and/or functional leg length; applicable tests include functional leg reach, leg clearance, and ejection clearance.

2) Construct boot blocks to simulate the bottom shape of the boot (separated into two separate pieces of equal thickness for the forward and heel sections to compensate for offset heels).

3) Make these block shapes from incompressible material in thicknesses of 0.5 and 1.0 in.

4) Attach blocks to the subject's boot by wrapping velcro straps or tape around the boot.

5) Be aware that boot blocks may hinder normal foot positioning, especially if pedal toe guards are used.

6) After the full range of body and seat positions are evaluated in each of the applicable tests, these same tests are repeated with the 0.5 in. and then with the 1.0 in. boot blocks attached. Make notes concerning the extrapolated body dimensions.

Blocking under the buttocks:

1) Buttock blocks increase sitting height, sitting eye height, and acromial shoulder height; applicable tests include overhead clearance, external field of view, internal field of view, and functional arm reach.

2) Construct buttock blocks in a wide flattened U-shape to simulate the contact areas of the buttocks and rear upper thigh.

3) Make these block shapes from incompressible material in thicknesses of 0.5 and 1.0 in.

4) Slide blocks underneath the subject's buttocks and position them to follow the contact area of the body onto the seat cushion.

5) Work around space conflicts between the blocks and any life support attachments or harness fittings. The blocks may need to be modified for proper fit.

6) After evaluating the full range of body and seat positions in each of the applicable tests, these same tests are repeated with the 0.5 in. and then with the 1.0 in. buttock blocks properly positioned. Make notes concerning the extrapolated body dimensions.

Blocking behind the hips/lower back:

1) Back blocks increase buttock-knee length and functional leg length; applicable tests include functional leg reach, leg clearance, and ejection clearance.

2) Construct back blocks in rectangular sections large enough to span the subject's hips yet small enough to fit within the confines of the seat edges.

3) Make these block shapes of incompressible material in thicknesses of 0.5 and 1.0 in.

4) Slide locks behind the subject's hips and lower back. Position them to allow as normal a sitting position as possible.

5) Work around space conflicts between the blocks and any life support attachments or harness fittings. Be aware of any unusual deviations that these flat blocks produce relative to a subject's curved lower back and usual sitting position.

6) After evaluating the full range of body and seat positions in each of the applicable tests, these same tests are repeated with the 0.5 in. and then with the 1.0 in. back blocks positioned. Make notes concerning the extrapolated body dimensions.

Recommended additional steps:

The effects caused by blocking should be more accurately recorded than merely assuming that a 1 in. block will increase a particular anthropometric dimension by 1 in. To accomplish this:

1) Locate the origin and termination of the subject's anthropometric dimension that is being artificially increased.

2) Decide which point is furthest from the block(s).

3) Assist the subject in obtaining a normal, upright sitting position with head level in the Frankfort Plane and hips/buttocks comfortably back into the seat. The Frankfort plane is an imaginary line connecting the upper surface of the ear's tragus (the cartilaginous flap located on the mid-forward part of the ear) to the infraorbital (lowest bony point on the rim of the eye socket).

4) Locate the chosen anthropometric point in three-dimensional space. Use either a device such as Space Vector or triangulate by measuring from cockpit hardpoints to the location.

5) Block the subject and assist him or her in replicating the original sitting position.

6) Locate the same point again in 3-D space.

7) Calculate the distance between the two locations. This will give a clearer indication of the actual artificial increase in that particular anthropometric dimension.

Overhead Clearance

Overhead clearance assessment determines the amount of clearance above and to the sides of the head. This is generally only an issue with larger subjects and is dependent upon sitting height and headwear dimensions.

Measure key dimensions of the helmet and other equipment beforehand. Measure appropriate height and width dimensions so that headwear dimensions can be added to subjects with bare head dimensions and so the dimensions can be subtracted from subjects wearing headgear. Include the widest, highest, and longest dimensions of the headwear, and reference each measurement to locations on the subject's head.

A thin layer of foam or other soft material may need to be taped to the top of the headwear to prevent scratching of the canopy or other overhead surfaces.

1) Move seat to the appropriate starting position (full down and aft, for example).

2) For aircraft with a moveable canopy, fully close and lock the canopy.

3) Orient all overhead areas and controls into their operational flight positions.

4) Place subjects in various head positions that are representative of aircrew needs in external field of view, internal crewstation field of view, flight demands, and use of crewstation controls. General descriptions of the subject's body position and the nearest contact points are aircraft-dependent and are made on a case-by-case basis. Some generic positions include:

a) Shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and the head leveled in the Frankfort plane.

b) Tilting head to left and right from the above position (to increase over-the-nose external field of view).

c) Bending to left and/or right for maximum over-the-side external field of view.

d) Twisting torso, neck, and head around for aft field of view (especially important for aircraft that may engage in air-to-air combat).

5) Take measurements with interior diameter calipers. Individually note and measure closest points between headgear and overhead structures for each subject body position.

6) Consider other relevant design characteristics. In an ejection seat aircraft, for instance, headwear should not be higher than canopy piercers in a plane parallel to the overhead canopy in the direction of ejection (spinal compression under ejection loads needs to be factored in, but it is beyond the scope of this report).

7) Repeat these procedures with blocking.

8) Move the seat to the next predefined seat position and repeat the above procedures at each position. Record all information on the blank forms included in appendix A.

External Field of View

External field of view assessment relates aircrew anthropometry to up/down elevation sightlines available at different left/right azimuth locations. It concerns the full population under consideration, with the primary anthropometric dimension being sitting eye height. Smaller people have more problems in attaining sufficient downward vision (due to a glare shield or the perimeter of the aircraft, for example), whereas larger subjects encounter more problems in attaining unobstructed upward vision (because of a canopy bow or overhead control panel, for example).

Define reference planes and angles before measurements begin, as follows:

1) For azimuth angles: define 0 deg as straight ahead (relative to the aircraft's centerline, fuselage, and/or flightpath) from the subject's eye position; negative degree values are toward the left or port side; positive degree values are toward the right or starboard side.

2) For elevation angles:

a) Define a "horizontal" 0 deg plane along the aircraft's orientation for straight and level cruise flight or along the aircraft's waterline (both may be similar).

b) Determine the desired aircraft attitude as well as the reference marks on the aircraft that define or are parallel to the aircraft's waterline.

c) Measure the current orientation of the aircraft waterline as the aircraft sits on the ground.

d) Compare the desired attitude and the current waterline orientation. Include differences in angle as a result of extra weight and test personnel on the aircraft. If the desired attitude is not parallel to the waterline, then factor in this difference after measurements are taken.

Once the aircraft's orientation is determined, testing is performed as follows:

1) Move the seat to an appropriate starting position (full down and aft, for example).

2) For aircraft with a moveable canopy, fully close and lock the canopy.

3) Orient all overhead areas and controls into their operational flight positions.

4) Place subjects in various head positions that are representative of aircrew needs in external field of view, flight demands, and use of crewstation controls. Make general descriptions of the subject's body position on a case-by-case basis. Some generic positions include:

a) Shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and head leveled in the Frankfort plane.

b) Tilting head to left and right from the above position (to increase over-the-nose external field of view).

c) Bending body to left and/or right for maximum over-the-side external field of view.

5) In each body position, take external field of view measurements. Measure elevation angles by having the subject use an Abney level and having the evaluator read off the angles. Abney level measurements are taken relative to the ground and they will need to be calculated relative to the aircraft's waterline or the desired aircraft flight orientation (as described above). Measure azimuth angles by viewing through an optical protractor with 0 deg set at the straight ahead reference (as described above).

6) Take field of view measurements from the subject's inboard-side eye through the canopy/windscreen out to the edge of the aircraft's perimeter. Take measurements at each body position by rotating the subject's head to view a minimum of the following directions. Take up and down field of view angles at each of these general azimuth areas (define the specific azimuth angles by the optical protractor):

a) Forward/over-the-nose.

b) 20-30 deg left.

c) 20-30 deg right.

d) Over-the-side left.

e) Over-the-side right.
f) Aft left.
g) Aft right.

7) Perform further measurements on any important visual obstructions and opaque protrusions into the external viewing area.

8) Encourage subjective comments from the subjects. Take measurements to quantify these comments and record this information together on the data sheets provided in appendix A.

9) Repeat these procedures with blocking.

10) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body and head positioning throughout all test phases. Record all information on the blank forms included in appendix A.

Internal Field of View

Internal field of view testing determines the level of biocular visual access provided for controls and displays. The primary anthropometric dimension is sitting eye height. Internal field of view can affect the entire population depending upon aircraft layout. Larger subjects tend to have more distinct problems because of their higher view down onto glare shields, light assemblies, protruding panels, and control mechanisms. But smaller subjects are more likely to encounter visual obstructions from the yoke or throttle. Body segments (knees, for example) can create visual blockage of lower controls and displays (requiring notation of the relevant anthropometric dimensions and their effects). Flight gear and accompanying equipment can also obstruct lower and surrounding areas.

1) Obtain multiple photocopies of a detailed crewstation layout diagram. These are used to make notes and shade in obstructed areas. The same photocopies are also used with external field of view notes.

2) Move the seat to the appropriate starting position (full down and aft, for example).

3) For aircraft with a moveable canopy, fully close and lock the canopy.

4) Orient all panels and controls into their operational flight positions.

5) Place subjects in various head positions that are representative of aircrew needs in internal field of view, flight demands, and use of crewstation controls. Head tilts can determine whether or not mild head motion will allow the subject to compensate for an obstruction by seeing around it. Make general descriptions of the subject's body position on a case-by-case basis. Some generic positions include:

a) Shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and the head leveled in the Frankfort plane.

b) Tilting head to left and right from the position described above (to increase over-the-nose external field of view).

c) Bending body to left and/or right for maximum over-the-side internal field of view around the sides of obstructions.

6) In each body position, take internal field of view measurements and observations. Subjects and evaluators should note each instrument, display, and control, the percentage of its useful surface area that is obstructed, the specific area of the item that is obstructed, the ease with which the subject can circumvent the obstruction, and comments regarding potential impacts on operational performance.

7) Take observations from the viewpoint of the subject's eye which has the least visual access, rotating the subject's head as needed for direct view of each different item.

8) Make further observations on any important visual obstructions and opaque protrusions into the internal viewing area.

9) Ensure that a thorough survey of the cockpit or crewstation is performed by the subject, including consoles, placards, and hidden controls.

10) Encourage subjective comments from the subjects. Take measurements to quantify these comments and record this information together on the data sheets provided in appendix A.

11) Repeat these procedures with blocking.

12) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body and head positioning throughout all test phases. Record all information on the blank forms included in appendix A.

Head-Up Display (HUD) procedures:

Become familiar with the variables of eye position up/down/forward/aft, the type of HUD, and any given HUD's particular optical characteristics. Because of their nature, HUD evaluations can be included in both internal and external field of view assessments.

1) Make photocopies of technical drawings showing the different HUD formats.

2) Obtain assistance from maintenance personnel or aircrew in displaying each HUD format.

3) Move the seat to an appropriate starting position (full down and aft, for example).

4) For aircraft with a moveable canopy, fully close and lock the canopy.

5) Orient all overhead areas and controls into their operational flight positions.

6) Place subjects in various head positions that are representative of aircrew needs in looking through the HUD "porthole" to see portions of the display. Describe the subject's body position on a case-by-case basis. Some generic positions include:

a) Shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), head leveled in the Frankfort plane, and looking straight ahead into the HUD.

b) Tilting head to left and right from the above position (to increase lateral HUD field of view).

c) Bending body to left and right for maximum HUD field of view out to the display's lateral perimeters.

d) Moving eyes up and down for maximum HUD field of view out to the display's lower and upper perimeters. Measure up/down movements of the eyes in 3-D space relative to cockpit hardpoints and a relevant plane (such as ejection rail plane, aircraft waterline, or other as appropriate).

e) Moving eyes in towards the display for maximum HUD field of view out to the display's perimeters. Forward/aft movements of the eyes are measured in 3-D space relative to cockpit hardpoints and a relevant plane (such as ejection rail plane, aircraft waterline, or other as appropriate).

7) In each body position, make observations about permissible HUD viewing and restrictions into its total field of view. Subjects and evaluators note each portion of the display, the percentage of its useful surface area that is out of view, the specific area of the item that is obstructed, and general comments regarding potential impacts on operational performance.

8) Take further observations on any important visual obstructions and opaque protrusions into the HUD viewing area.

9) Encourage subjective comments from the subjects. Take measurements to quantify these comments and record this information together on the forms provided in appendix A.

10) Repeat these procedures with blocking.

11) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body and head positioning throughout all test phases. Record all information on the forms provided in appendix A.

Functional Arm Reach

Functional arm reach testing determines the degree to which a person can properly, efficiently, and comfortably reach and actuate crewstation hand control mechanisms. Reach capability is determined for the flight stick/yoke, throttle, input devices, and all primary and secondary buttons, switches, handles, levers, etc. The primary anthropometric dimensions are functional arm reach and sitting acromial height. Secondary dimensions include bideltoid diameter, shoulder-elbow length, and hand measurements. The envelope of functional arm reach is generally only a concern for subjects with smaller functional arm lengths. The worst level of accommodation frequently occurs for those with a combination of small functional arm reach and large sitting acromial height.

1) Obtain multiple photocopies of a detailed crewstation layout diagram. These are used to make notes and shade in obstructed areas.

2) Move the seat to an appropriate starting position (full down and aft, for example).

3) Orient all panels and controls into their relevant operational flight positions.

4) Have the subject maintain the following body positions for each control mechanism in the cockpit. It is more expedient to perform all functional reach measurements to all controls for one Zone at a time. After all three Zones are simulated for all controls, the subject then moves to the next seat test position.

a) Zone 1, Restraint Harness Locked: Subject's body is fully restrained, with no stretching of arm or shoulder muscles. This position simulates takeoff, catapult launch, and high-g maneuver situations.

b) Zone 2, Restraint Harness Locked: Subject's body is fully restrained but allowed maximum stretch of arm and shoulder muscles to reach each control mechanism. This position simulates general flight conditions with an automatic or manual locking restraint system.

c) Zone 3, Restraint Harness Unlocked: Restraints are on the subject's body, but unlocked and loosened. Subject uses maximum stretch of arm, shoulder, and torso to actuate control mechanisms. This position simulates normal flight conditions without any locked restraints or g-induced loads imposed on the aircrew's body.

5) To measure miss distance: Have the subject simulate the position needed to actuate a control and extend his or her arm directly towards it. Measure the distance from the hand's interface point to the control mechanism's interface point. This represents miss distance.

6) To measure surplus distance:

a) Roll up the sleeves of the subject's flight gear.

b) Space small ink marks evenly around the perimeter of the forearm approximately 5 in. above the wrist. This acts as a reference band.

c) Before the subject attempts to actuate a close control, the subject outstretches his or her hand into a position similar to that which would be used on the particular control. The subject simulates the appropriate grasping, pulling, pushing, or rotating position of the hand.

d) Take a measurement from the band on the forearm to the hand's interface point. This provides the normal hand interface distance from the forearm band.

e) The subject then directs his or her arm toward the control mechanism, but also swings the hand down at the wrist (since this is a surplus distance measurement, the hand would "go through" the control at a maximum reach position).

f) Measure the distance from the forearm band to the control interface.

g) Surplus distance will equal the forearm band/hand interface distance minus the forearm band/control interface distance.

7) Make further observations on any functional reach obstructions and protrusions into crewstation space.

8) Encourage subjective comments from the subjects. Take measurements to quantify these comments and record this information together on the forms provided in appendix A.

9) Repeat these procedures with blocking.

10) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body positioning throughout all test phases. Record all information on the forms provided in appendix A.

Functional Leg Reach

Functional leg reach assessment determines the relationship between leg dimensions and the ability to fully actuate all foot controls. Anthropometric dimensions of interest include functional leg length, buttock-knee length, sitting knee height, and boot size. Functional leg reach is usually only a concern for smaller subjects. Related problems for large subjects generally result from extremely confining crewstation space and will overlap with leg clearance problems (see below).

1) Measure the foot control adjustment range before measurements are taken. Locate the foot control's plane of motion relative to the waterline, seat, or crewstation floor, as appropriate. Count any notched positions, and measure and note the distance between notches.

2) Move the seat to an appropriate starting position (full down and aft, for example).

3) Orient all panels and controls into their relevant operational flight positions.

4) Place subjects in an upright, comfortable body position. Position shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and head leveled approximately in the Frankfort plane.

5) Adjust the yaw pedal carriage and/or other foot mechanisms to their full aft position closest to the subject.

6) While maintaining a comfortable sitting position, each subject attempts to actuate foot controls through their full ranges of motion. For yaw pedals with brakes, the pedals are pushed through their full left and right forward throw. If the subject can accomplish this with full knee extension but no forward movement of the hips or torso, the subject then attempts to rotate the toe brakes at the full throw positions.

7) Miss distance is measured if the subject has difficulty in obtaining any of these foot control positions. An evaluator may be required to assist and depress the foot control fully. The direct miss distance between the interface point on the underside of the subject's footwear and the interface point on the foot control is then measured.

8) If subjects are capable of reaching all foot controls, then obtain subjects with shorter functional leg lengths.

9) Surplus distances are useful for data extrapolation. If foot control locations are adjustable, then surplus distances are measured by first defining the foot control/footwear interface point in 3-D space. Move the control away from the subject's foot enough to permit full extension of the subject's leg. Measure the new location of the foot control/footwear interface point in 3-D space. The distance between these two points represents surplus distance.

10) Repeat the above procedures at each seat position for each foot control and for each foot control's different operational positions.

11) Repeat these procedures with blocking.

12) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body positioning throughout all test phases. Record all information on the forms provided in appendix A.

<u>Leg Clearance</u>

Leg clearance testing relates leg dimensions to the amount of clearance between different parts of the leg and hardpoints in the cockpit/crewstation. The primary anthropometric dimensions are functional leg length, buttock-leg length, sitting knee height, boot size, thigh circumference, and lower thigh circumference. Leg clearance is generally only an issue with large subjects. However, small subjects may also be a concern if a forward/aft adjustable seat needs to be moved forward and this results in thigh obstruction to the flight stick range of motion or lower ejection handle access. Also, small but bulky subjects may experience similar problems due to girth.

1) Measure the foot control adjustment range before measurements are taken. Define the foot control's plane of motion relative to the waterline, seat, or crewstation floor, as appropriate. Count notched positions, and measure and note distances between notches. This information should already have been recorded above for functional leg reach assessment.

2) Move the seat to an appropriate starting position (full down and aft, for example).

3) Orient all panels and controls into their relevant operational flight positions.

4) Place subjects in an upright, comfortable body position. Position shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and head leveled approximately in the Frankfort plane.

5) Adjust the yaw pedal carriage and/or other foot mechanisms to their full aft position closest to the subject.

6) While maintaining a comfortable sitting position, each subject attempts to actuate the foot controls through their full ranges of motion. For yaw pedals with brakes, the pedals are pushed through their full left and right forward throw. Other controls, such as foot switches, are also actuated and tested.

7) Take measurements between points of near contact for each foot control and for each foot control position. For example, a measurement may be appropriate between the lower edge of the main instrument panel and the subject's shin just below the knee. Describe the near points as explicitly as possible on the blank forms included in appendix A.

8) If foot controls have a range of adjustability or several different operational positions, then leg clearance is evaluated at each control position or at increments along its range of motion.

9) Repeat these procedures with blocking.

10) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body positioning throughout all test phases. Record all information on the forms provided in appendix A.

11) After measuring distances between particular points, these same points are then used consistently at each seat position and at each foot control position. Do this even if the possibility of contact looks unlikely as the seat and foot controls get moved into new positions. Following this approach aids in data interpolation/ extrapolation after testing is completed.

Thigh Gap

Thigh gap assessment relates leg dimensions to distances encountered between the lower thigh and the seat when foot controls are actuated throughout their range of motion. The primary anthropometric dimensions are functional leg length, buttock-knee length, sitting knee height, thigh circumference, and lower thigh circumference. Thigh gap is mainly a concern for larger subjects in ejection seat aircraft. Insufficient thigh gap for full actuation of foot pedals can also be a problem for small subjects.

1) Measure the foot control adjustment range before measurements are taken. Locate the foot control's plane of motion relative to the waterline, seat, or crewstation floor, as appropriate. Count notched positions, and measure and note the distances between notches. This information should already have been recorded above for functional leg reach assessment.

2) Move the seat to an appropriate starting position (full down and aft, for example).

3) Orient all panels and controls into their relevant operational flight positions.

4) Place subjects in an upright, comfortable body position. Position shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and head leveled approximately in the Frankfort plane.

5) Adjust the yaw pedal carriage and/or other foot mechanisms to their full aft position closest to the subject.

6) While maintaining a comfortable sitting position, each subject attempts to actuate the foot controls through their full ranges of motion. For yaw pedals with brakes, the pedals are pushed through their full left and right forward throw. Other controls, such as foot switches, are also actuated and tested.

7) Take measurements of thigh gap for each foot control and for each foot control position. Measure the linear distance from the hard seat pan edge to the closest point on the underside of the thigh perpendicular to the femur with an inside diameter caliper or linear scale. Place slight pressure on the flight gear to get the caliper or linear scale near the level of the skin.

8) If foot controls have a range of adjustability or several different operational positions, then evaluate leg clearance at each control position or at increments along its range of motion.

9) Repeat these procedures with blocking.

10) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body positioning throughout all test phases. Record all information on the forms provided in appendix A.

Ejection Clearance

Ejection clearance testing determines the clearance available upon ejection from aircraft hardpoints to aircrew with specified anthropometric dimensions. Ejection clearance is generally only a concern for larger subjects. Primary anthropometric dimensions are functional leg length, buttock-knee length, sitting knee height, boot size, and bideltoid diameter.

1) Arrange a full seat pull, although the seat may not need to be pulled completely free from the ejection rail.

2) Orient all panels and controls into their relevant operational flight positions.

3) Determine the ejection seat rail angle using a digital (or leveling) protractor.

4) Place subjects in an upright, comfortable body position. Position shoulders back but not rigid, buttocks/hips back into the seat cushion (i.e., no slouching), and head pressed lightly against the headrest. Position thighs flat against the seat cushion. Have feet dangle freely.

5) If a seat pull cannot be arranged, yardsticks or a flat board are placed alternately at the subject's knees and feet to indicate the path that these would take in an ejection. Extend the yardsticks and boards from the subject's potential contact points parallel to the ejection rail.

6) As the seat is pulled up the rail (or as the evaluator notes points along the yardsticks/board), take measurements at all points where the body contact point and the area of potential contact are closest. Explicitly describe body and crewstation locations in the forms provided in appendix A.

7) Note potential contact areas to the head and arms in a similar fashion. Assessments of contact to the head require that the subject be placed in an operational seat with the canopy closed. Due to interference from the closed canopy, the subject may need to make the clearance measurements on himself/herself with an interior diameter caliper or linear scale. Provide guidance at all times. Interpretation and notation of the clearance measurements are performed by the evaluators, including an explicit description of the near contact points on the headgear and crewstation from which the measurements were taken. Nearest contact points may change as the seat is moved up, and this is also noted.

8) Repeat these procedures with blocking.

9) Move the seat to the next predefined seat position and repeat the above procedures at each position. Watch the subject's body positioning throughout all test phases. Record all information on the forms provided in appendix A.

Other Areas for Aircrew Anthropometric Accommodation Assessment

Although the most prevalent areas of anthropometric accommodation assessment are already discussed, there may be other areas of concern for a particular aircraft. These are briefly mentioned here. They are adapted to the test sessions using the ideas and cautions for the methods described in this report. Some examples of other anthropometric dimensions that may have an impact include:

a. Bideltoid diameter: may be a factor with close canopy rails or structures protruding into the crewstation.

b. Aspects of Hand Size: related to palm fit and curl around throttle, fit on yoke, and access to switches, buttons, and levers.

c. Waist depth: can degrade flight stick range of motion or hinder access to the ejection handle.

d. Thigh Circumference: can degrade flight stick range of motion, hinder access to ejection handles, and interfere with flight gear or other attached equipment.

e. Sitting Hip Breadth, Buttock Circumference, and Sitting Buttock Circumference: affect fit into the "bucket" of the seat and clearances with survival gear and fittings.

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